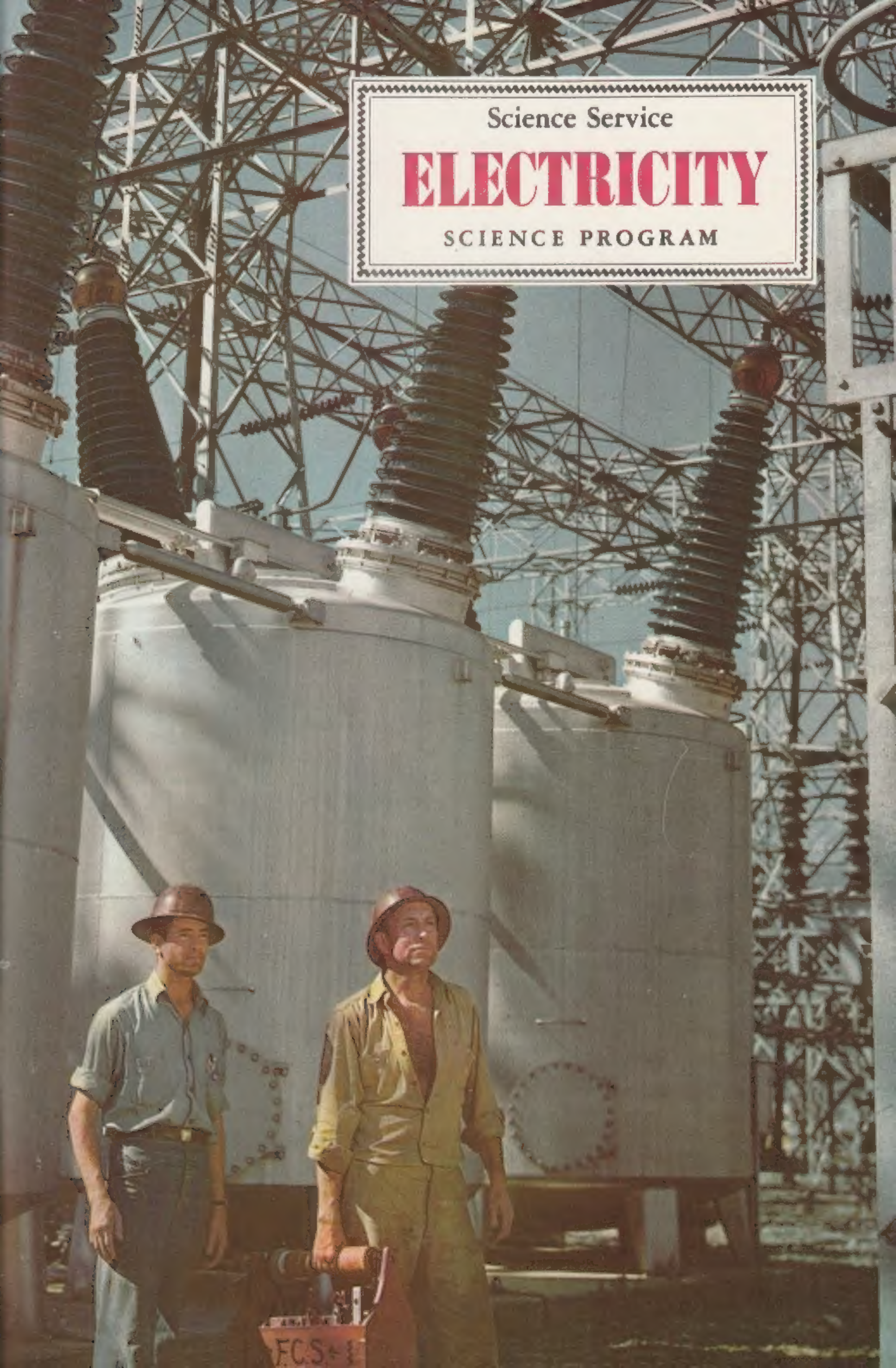
Science Service

ELECTRICITY

SCIENCE PROGRAM



ELECTRICITY

SCIENCE PROGRAM

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Science Service

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Electricity in Action

HUDDLED IN THE DARKNESS of his cave, early man shrank in terror as a blinding streak of light struck a tree on the nearby mountain. A deafening roar followed, reverberating through the canyon below. The man was frightened. He didn't understand.

The earth has been bombarded by these powerful bolts of lightning ever since its fiery birth some 4.5 billion years ago. Early thinkers were puzzled by this spectacular display of natural energy. For centuries they wondered: What is it? How can we defend against it?

Today, "nature's artillery" is at least partially understood. As Benjamin Franklin showed in 1752, lightning is electricity. Knowledge of electricity has permitted man to defend his property, his home and his very life from lightning. But much more than that . . .

Our present-day lives now are brighter, easier and healthier because of electricity. Although we are not always aware of its contributions to modern life, we are surrounded by evidence of electricity at work. Clean and convenient power is available in our homes, schools and factories at the flick of a switch. Electricity illuminates our homes, warms us when we are cold, cools us when we are hot, washes our dishes and clothes,

A far cry from the old wooden paddle wheel, this Brazilian overshot bucket wheel at São Paulo utilizes a waterfall as the prime step in producing electricity. Here the wheel is being repaired.

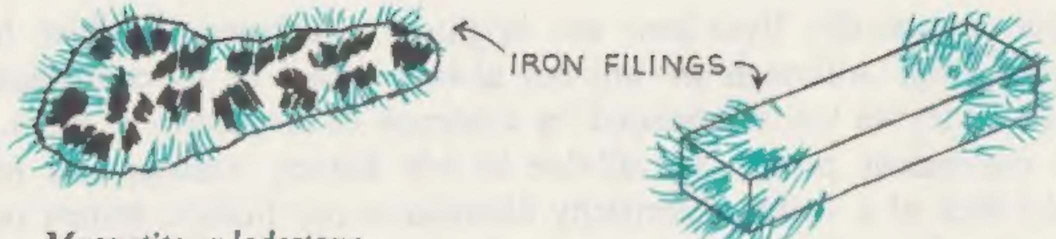
1. TURBINE BUCKET WHEEL

cooks and protects our food, powers our factories and spreads ideas through instant world communication. Electricity! Just what is it?

At the Start: Magnets

LET'S GO BACK TO ABOUT 100 B.C. when a natural black mineral was found that had a unique property. Called *magnetite* after the ancient city of Magnesia in Asia Minor, where it was found, this material had the property of attracting small pieces of iron. This force of attraction is now called *magnetism*. It took centuries for science to discover that magnetism and electricity are closely related.

An iron bar can be made into a magnet by stroking it with a piece of magnetite. One of the greatest contributions to navigation and explora-



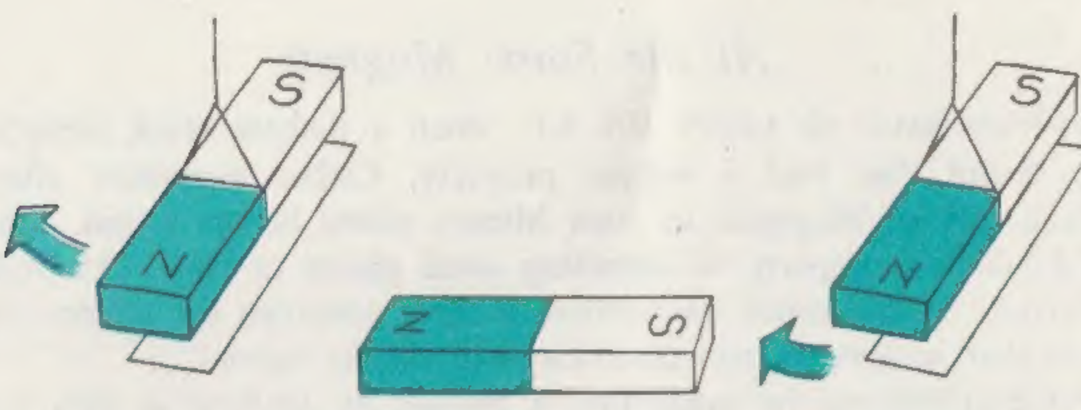
Magnetite or lodestone is a natural magnet

Artificial magnet can be made from an iron bar

More iron filings gather at the ends of a magnet than at the middle. These ends are called poles, identified as north or south.

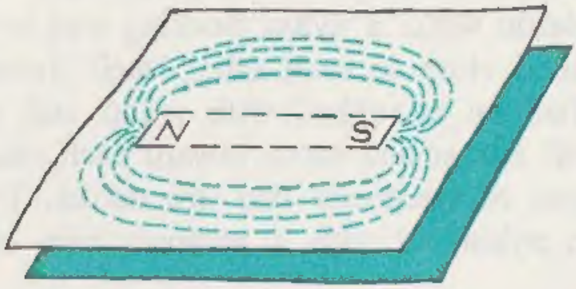
tion of the world was the compass, which is merely a small magnet delicately balanced to permit free rotation. The earth itself is a magnet, with a magnetic pole near the "north" pole shown on maps. A compass or a freely suspended magnet will normally align itself so that it always points to the same spots on the earth: the magnetic north and south poles. The end of the magnet that points to the north magnetic pole is called the *north-seeking* or, more conveniently, the *north pole* of the magnet. The other end is the *south-seeking* or *south pole.*

Any person who has ever experimented with a pair of bar magnets knows that *like poles* of two magnets repel each other, while *unlike poles* attract each other. Bodies charged with electricity behave in much the same way.

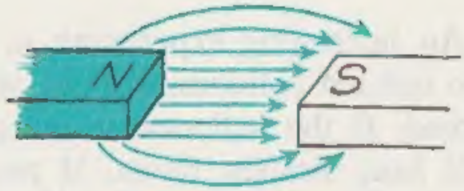


LIKE POLES REPEL

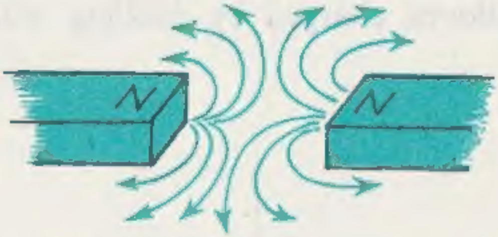
UNLIKE POLES ATTRACT



Iron filings sprinkled on a sheet of paper held over a magnet will trace the magnetic field



MAGNETIC FIELD OF UNLIKE POLE ATTRACTING



MAGNETIC FIELD OF LIKE POLES REPELLING

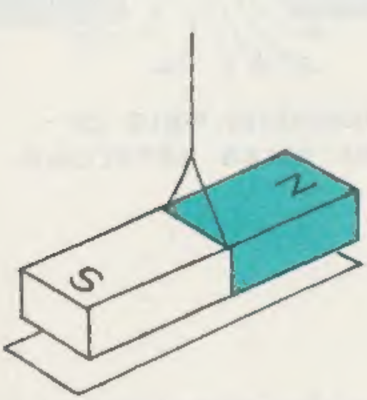
A magnet attracts iron particles not only at the poles, but in a region all around the magnet. If a piece of paper is placed over a magnet and iron filings are sprinkled and the paper agitated slightly, it will be found that the filings tend to align themselves in a distinct pattern around the magnet. This pattern and space where magnetic effects are felt is called the *magnetic field.*

A New Science

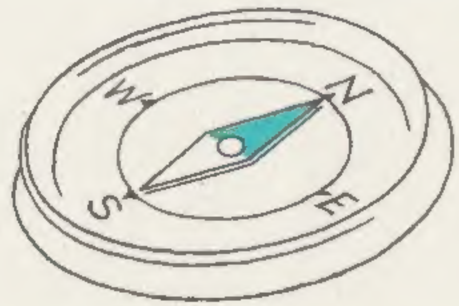
THE EARLIEST RECORDED THOUGHTS about electricity are attributed to the Greek philosopher Thales, who, in about 600 B.C., observed that after an amber rod was rubbed briskly with a piece of fur, cloth or other dry substance, it would attract small pieces of feathers and straw just as a magnet attracts iron filings. Pliny the Younger, a Roman who died in 144 A.D., duplicated this simple experiment but, like Thales, was unable to explain it. Today we know this as a manifestation of what we call *static electricity.*

Static electricity is electricity "at rest". When a person brushes his hair on a dry winter's day, the hair tends to stand on end. Evidently each hair is charged with the same kind of electricity and each hair is repelling every other.

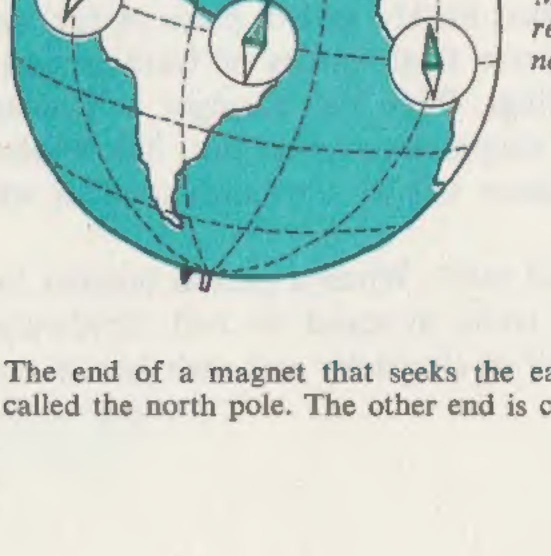
An interesting experiment in static electricity can be performed with two inflated balloons, a piece of plastic wrap, a nylon stocking and some thread. If the balloons are suspended close to each other, their threads will hang straight down. If one balloon is rubbed with nylon and the other with the plastic wrap, they will attract and move toward each other. The balloons have taken on charges of electricity that are unlike. Two balloons charged by rubbing with nylon, or with a person's hair, will



Magnet free to swing aligns itself with earth's magnetism

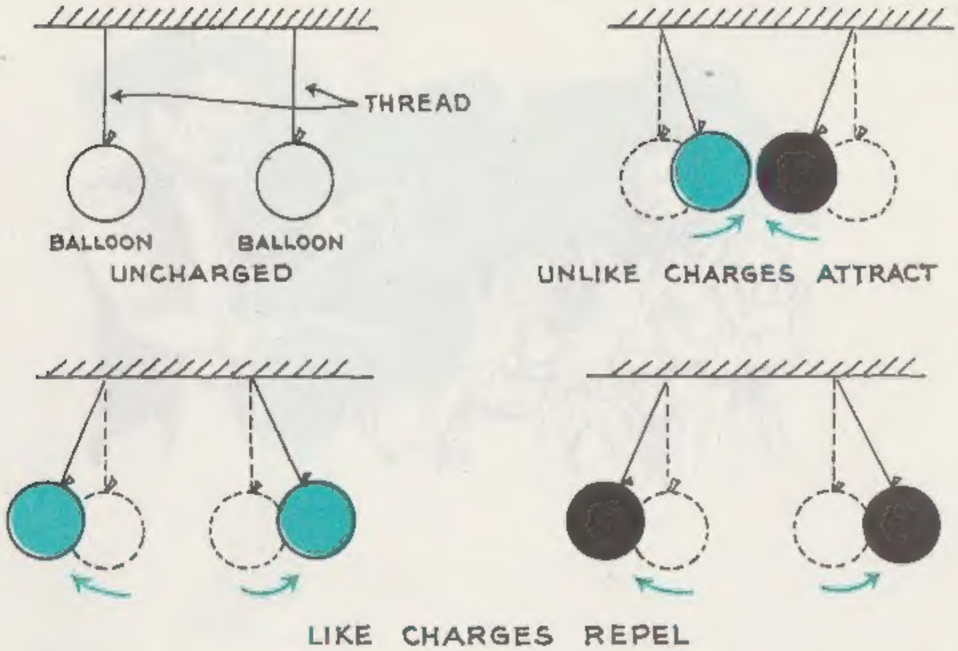


A compass is a free-swinging magnet



The earth itself is a big magnet. Magnetic north pole is slightly removed from the geographic north pole shown on maps

The end of a magnet that seeks the earth's magnetic north pole is called the north pole. The other end is called the south pole.

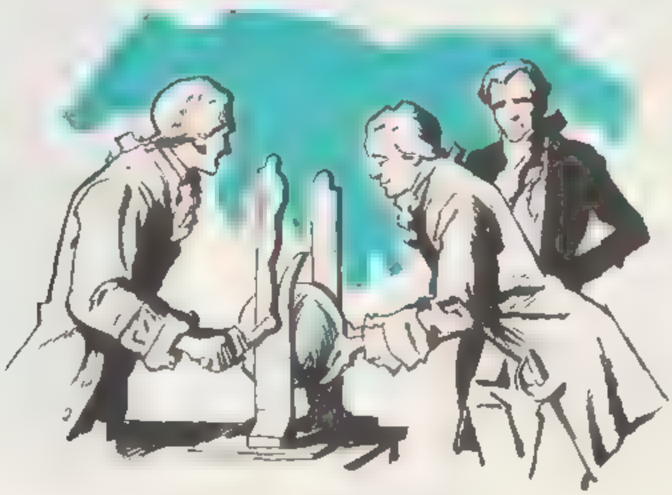


be found to repel each other. Two balloons charged by rubbing with plastic wrap will repel each other. Evidence shows that unlike charges attract each other and like charges repel.

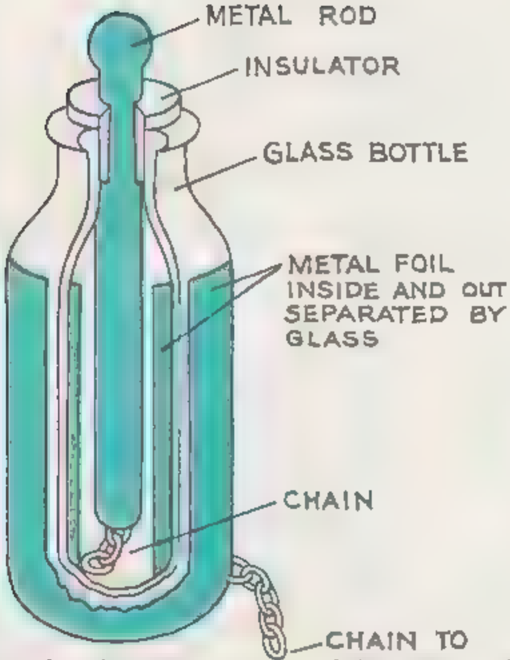
This smiling student received a large but quite harmless shock after touching an electrostatic generator. Anyone's hair would stand on end with 300,000 volts.

In the late 1500s Queen Elizabeth I had a brilliant court physician named William Gilbert, who had an inquiring, scientific mind. He repeated the demonstrations of Thales and Pliny and named the science of studying these phenomena *vis electrica* after the Greek word elektron, which means *amber*. The word *electricity* was derived from this term and has been used ever since to describe the science of charged bodies. Like his predecessors, Gilbert knew *what* happened, but he didn't know *why*.

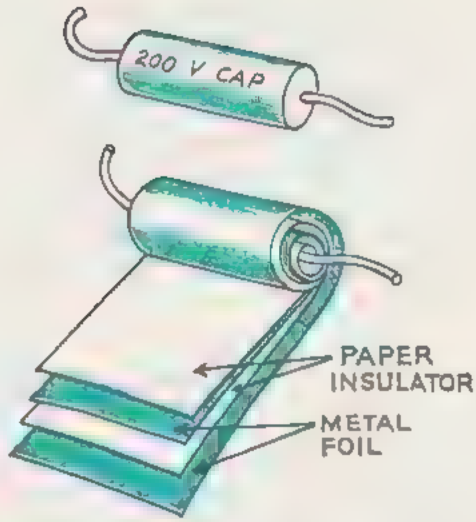
Charles Du Fay is credited with coining the word *conductor* for any material that will carry a charge from one body to another. A *nonconductor* or *insulator* is a substance that will not carry a charge.



Otto von Guericke showing two friends how his friction machine made electricity.



A Leyden jar is a capacitor (or condenser)



One wire is attached to each sheet of metal foil

The common radio capacitor is made of metal foil and paper, rolled up and sealed.

The First Friction Machines

In the middle of the seventeenth century, scientists throughout Europe were beginning to perform electrical experiments. But rubbing two objects together was a slow way of making electricity. Fortunately, Otto von Guericke created a device that not only made electricity much more conveniently but in appreciable quantities as well. In 1663 this German inventor created an electrical-friction machine. He made a sphere of sulphur "as big as an infant's head", inserted an iron axle through the midpoint and attached a wooden crank. By rubbing the sulphur with his hand as he cranked, Von Guericke showed that the sphere became electrified. Bits of paper would stick to it, and he could transfer the charge to other balls of sulphur.

Many other "friction machines" followed, including one built by Sir Isaac Newton and one by F. Hauksbee in 1706 that used a rotating glass globe with a rubbing chain for collecting the charge. The Wimshurst machine, still used in schools for static-electricity demonstrations, was invented by James Wimshurst in 1878.

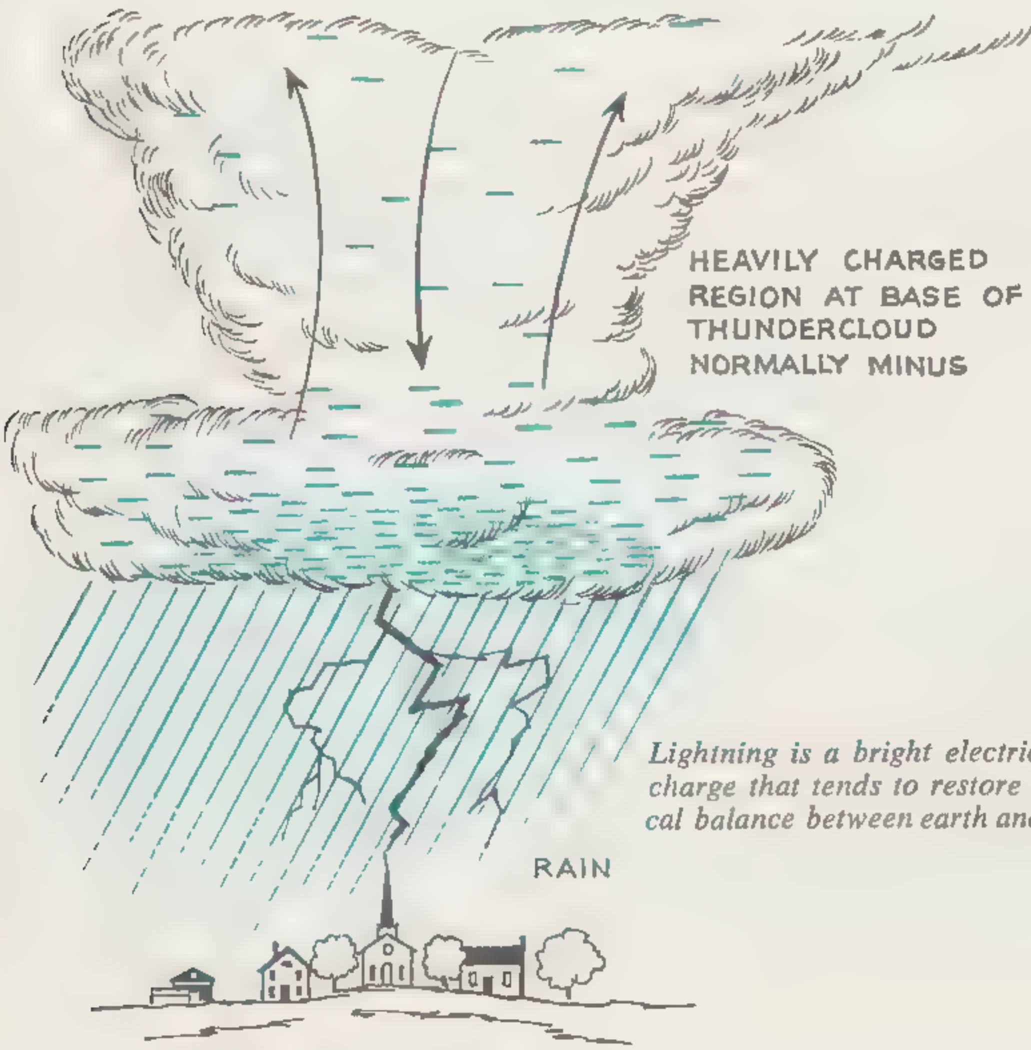
In 1745 a device was made that could store considerable charges for long periods of time. Called the *Leyden jar,* it could be "filled with electricity", carried around and discharged at will. It became a valuable

experimental tool. Credited with this invention is the Dutchman Pieter van Musschenbroek, who had experimented at the University of Leyden with wrapping metal foil around a glass bottle. After he charged his creation with electricity from a friction machine, Van Musschenbroek found that the jar could truly store electricity: he touched the top and received a severe shock in the arm. Devices that can be reservoirs for electrical charges are called *capacitors* or *condensers.*

Pioneer: Benjamin Franklin

BENJAMIN FRANKLIN became interested in electricity in 1746. He read of the contributions of earlier scientists and wanted to obtain a friction machine and a Leyden jar so that he too could make investigations. Entering this field of science with a fresh point of view, Franklin believed that electricity was an element common to all bodies and that there were not "two kinds of electricity" as some people had thought. His simple but significant conclusion was that the phenomena previously attributed to two kinds of electricity were merely the result of

having bodies charged with more or less of the same kind of electricity. He explained that rubbing merely transferred electricity from the rod to the cloth or vice versa. So Franklin said that if a body had more electricity than another, it had a surplus of charge. He called this type of charge *plus* or *positive*. If one body had less charge than another,



Lightning is a bright electrical discharge that tends to restore electrical balance between earth and cloud

it had a deficiency of electricity and was a *minus* or *negative*. Electricity, he said, would therefore flow from plus (a surplus) to minus (a deficiency), like water trying to seek its own level. Up to this point we are indebted to Franklin. However, as he was unable to see the actual

charges, Franklin's decision to call a surplus of charges "plus" was arbitrary. We shall see later that he was wrong. It was a bad guess!

The Kite Experiment

FRANKLIN'S MOST MEMORABLE CONTRIBUTION to science was his theory that lightning is electricity, and his subsequent demonstration of this theory. His famous kite experiment of 1752 showed that the electricity of lightning is the same kind of electricity as that from rubbed rods or friction machines.

Franklin made a kite on top of which he mounted a small metal rod. To the bottom of the kite string he attached an ordinary door key. Between the key and his hand was a piece of silk ribbon. On a stormy June day he flew his kite near a thundercloud. No flash of lightning came down the string, but Franklin noticed that the frayed ends of the string were bristling away from each other. Then he put his hand near the key and was delighted to discover that a visible spark jumped between the key and his knuckle. He collected some of the electricity from the string in a Leyden jar and later showed that it behaved in the same way as any other electricity.

We know today, of course, that Ben Franklin was lucky that his experiment had a happy ending. If he had used a good conductor like a copper wire instead of a string, he might have been electrocuted.

During this period of Franklin's interest in electricity he thought of the lightning rod as a means of protecting buildings from lightning damage. He suggested correctly that lightning strokes were sudden discharges of electricity between thunderclouds and the ground due to their vast differences in charge. Based upon his ideas, the world's first lightning rods were fitted to buildings in Philadelphia. They demonstrated that if lightning does strike, the lightning rod system protects a building from damage by providing an easy conducting path to the ground.

Thunder and Lightning

A THUNDERCLOUD IS A VIOLENT TURMOIL of moist air. Rising warm air meeting cool air results in precipitation that causes different charges of electricity in different parts of the cloud. The falling rain or hail usually leaves a surplus of electricity in the bottom of the cloud compared with the ground below. The air between the cloud and the ground is a nonconductor or insulator and keeps the cloud charges from getting

One of the world's largest lightning arresters. These three 29-foot-high tripod legs act as a greased skid for lightning, giving it an easy path to the ground, thus protecting delicate measuring instruments and transformers. Each leg is tied to the other by large metal rings to prevent any one from becoming overloaded.

to the ground. But when the electrical difference becomes too great, this insulation fails and a small stream of electrical particles manages to pass between the cloud and the ground. Almost instantly huge amounts of electricity rush through the path created by the streamer. The tremendous energy of the electricity heats the air and makes it glow. Light is created. Lightning is, in effect, a giant spark. The heated air expands explosively, creating the noise called thunder.

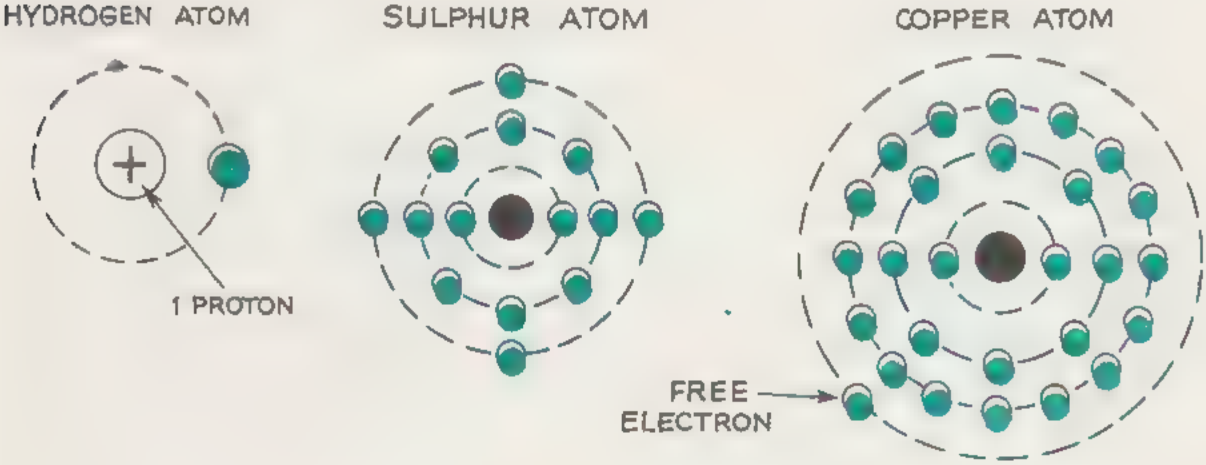
2. ATOMIC POWER PLANT

One of England's unconventional electric generating stations is located at Calder Hall, in Cumberland. Atomic power is used to drive its generators.

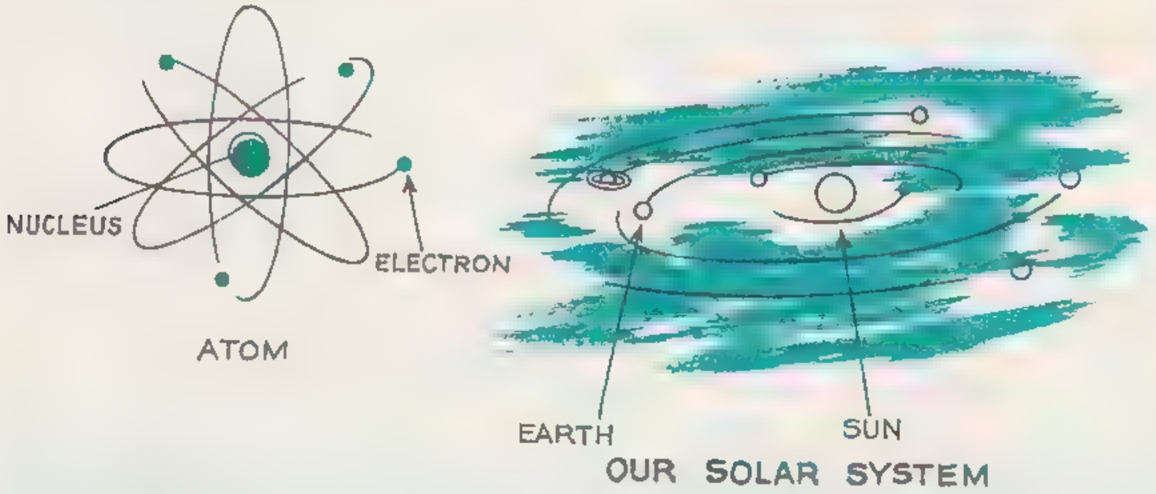
Atoms and Electrons

A TRUE UNDERSTANDING of the nature of electricity and the flow of electrical particles was made possible by the theories of Dalton, Thomson, Rutherford, Bohr and Langmuir around the start of the twentieth century. Each one built upon the knowledge of his predecessors. The result of their work is the currently accepted *atomic theory*.

LEFT: Hydrogen is the simplest element. Its nucleus is made up of one proton. Its atom has one electron. CENTER: Sulphur is a poor conductor. Its nucleus contains 16 protons, its innermost shell holds 2 electrons, the next orbit 8 electrons, and the outermost shell 4 electrons. RIGHT: Copper is a good conductor. Its nucleus contains 29 protons, its innermost shell holds 2 electrons, the next orbit 8 electrons, and the next 16. The outermost shell has only one electron. A copper atom readily gives up this free electron.



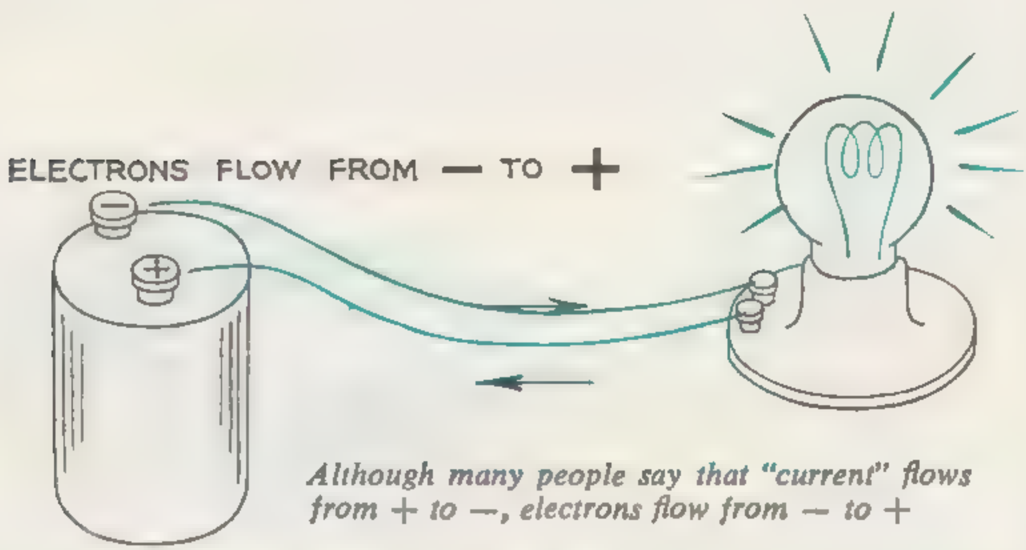
John Dalton, first of the great English physicists, proposed a scientific atomic theory in 1803 which stated that all matter is composed of tiny entities called atoms. All atoms of any single element are identical: all oxygen atoms are alike, all copper atoms are alike, and the atom of each element is different from the atom of every other element. The atom, Dalton felt, was the smallest particle of matter and was therefore indivisible.



An atom is similar to a miniature "solar system"

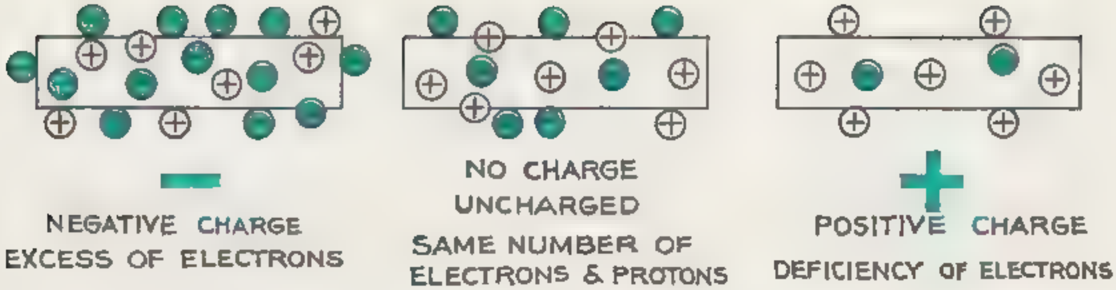
In 1897, however, J. J. Thomson concluded that atoms were divisible and that each atom was in reality a miniature universe with moving parts similar to our solar system. He thought of the core or nucleus of the atom as a ball of positive charge. Whirling around it like planets were the basic particles of negative electricity, later named *electrons* after the suggestion of Johnstone Stoney. Thomson did not attempt to explain the composition of the nucleus but did say that the gain or loss of one electron changed the properties of an atom. Ernest Rutherford suggested in 1910 that this core, or nucleus, was made up of protons and neutrons, a proton having a charge exactly opposite to an electron. Neutrons have no charge at all. The Rutherford atom design, then, consists of a tight nucleus of protons and neutrons with a "solar system" of electrons revolving around it. The whole atom is held together by electrical balance. The heavy protons and neutrons, each of which weighs 1,836 times as much as an electron, stay in the nucleus, but the whirling electrons are free to move.

Rutherford's ideas were expanded by the famous Danish physicist Nils Bohr, who stated that electrons travel in regular elliptical-shaped orbits and that when an orbit is changed some energy is released. American scientist Irving Langmuir showed that there are in effect regular spherical "shells" or orbit paths around the nucleus, each with a certain capacity

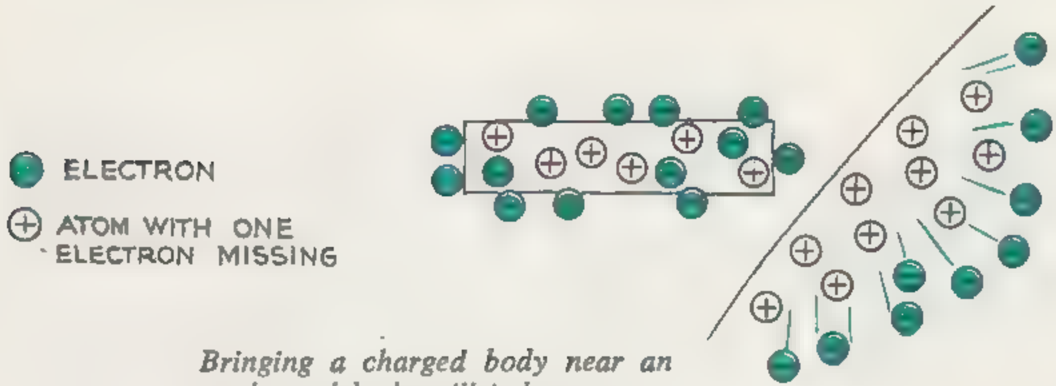


Although many people say that "current" flows from + to —, electrons flow from — to +

IMPORTANT: In this booklet when we talk of "current" we mean the "flow of electrons" which move from minus (—) to plus (+).

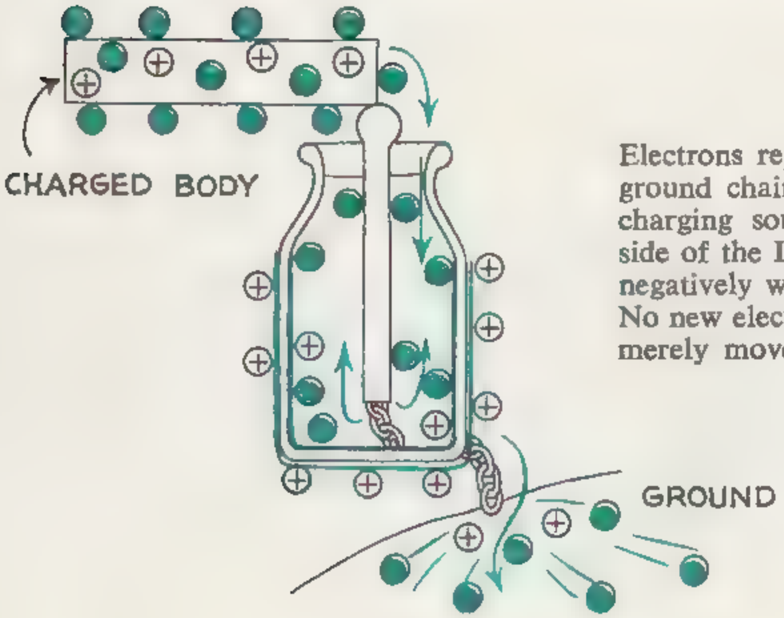


The number of protons does not change, the electrons are merely moved around



Bringing a charged body near an uncharged body will induce an opposite charge on the other body

CHARGING A LEYDEN JAR



Electrons repel each other. When the ground chain is disconnected and the charging source is removed, the inside of the Leyden jar is then charged negatively with respect to the outside. No new electrons are created; they are merely moved around.

to hold electron tenants. The atom is stable when the shells are complete. If a shell's quota of electrons is not quite complete, the atom attracts additional electrons to fill the ranks. If the shell is almost empty, the atom may pass the few electrons it has in that shell along to other atoms. Elements with just one or two electrons in the outermost shell are generally good conductors of electricity because they pass electrons along. The outer electrons are called *free electrons*. Atoms lacking only one or two electrons in the outer shell attract electrons to complete the shell and tend to be poor conductors. Atoms with complete outer shells generally are such poor conductors that they make good insulators.

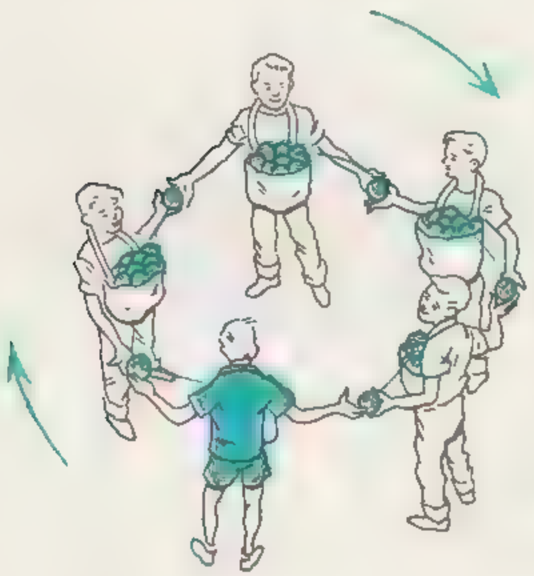
How Electrons Behave

ELECTRONS, THEN, ARE FREE TO MOVE from atom to atom if they are pushed—while protons are not. The electron is so small that even the world's most powerful microscope cannot reveal it. Exactly what the electron is made of is still a matter of conjecture.

But whatever its exact composition, scientists have a good idea of how the electron behaves. It attracts protons and repels other electrons. It pushes the electrons away just as like poles of magnets repel each other.

If a highly charged body with an excess of electrons is brought near another body—even if it doesn't touch—it will repel the electrons near it. This is charging by *induction*.

When a body is charged with more electrons than it had before, the electrons distribute themselves over the surface of the body because they



Passing balls in a circle is similar to the passage of electrons from atom to atom when a "current" flows in a conducting circuit. The boy in the colored suit passes the first ball.

repel each other. If a long wire or conductor is given an extra supply of electrons at one end, the electrons will flow down the wire until they are evenly distributed.

When electrons flow, therefore, they go from a region where there are many electrons to a region where there are fewer electrons. They flow from a surplus to a deficiency. This is directly opposite to Franklin's original idea.

Today, by force of habit, people still say that "electrical current flows from plus to minus"—even though this is wrong. Always keep in mind that although "current" is said to go from plus to minus, the electrons—which are really the things that are moving—go in the opposite direction.

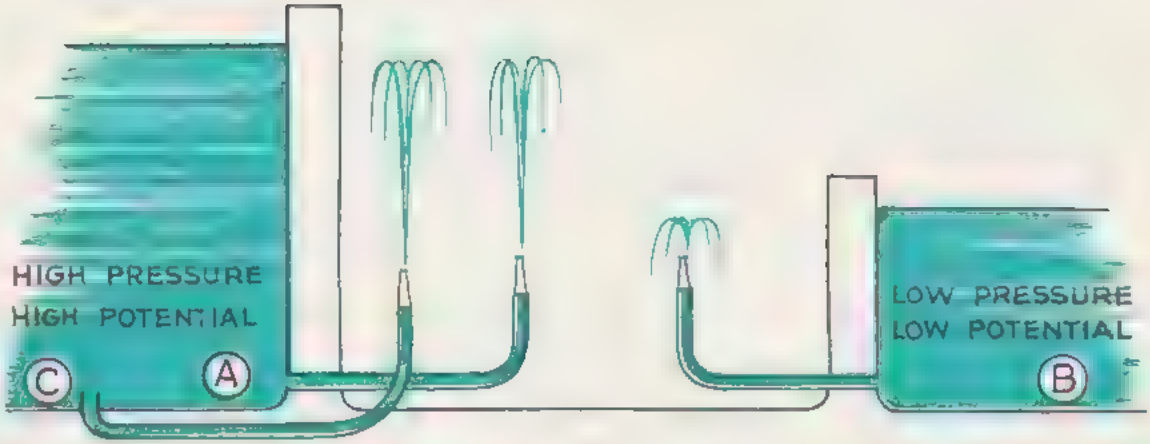
Flow at Speed of Light

THE PASSAGE OF ELECTRONS along a conductor has been likened to passing a ball (electron) around a circle of boys (atoms), each of whom already has a bag full of balls (electrons). If you hand a ball to the first boy, he takes it with one hand and puts it in his bag. Simultaneously, he takes any ball from the bag with his other hand and passes it to the next boy. The instant you give the first boy a ball you receive a ball from the last boy, but the ball that comes to you on the end of the line is not the same ball you give the first boy. Although the actual speed of a particular, marked ball moving around the circle may be quite slow, the effect of pushing the ball to the first boy is felt immediately by the last boy. Electrons making their way through a mass of atoms in a conductor are passed along in much the same way. The effect of electron motion (passing the balls) is transmitted through a conductor at almost the speed of light (186,000 miles per second), but the average speed of any particular electron (or marked ball) moving along a conductor may be only one inch per second.

The electrons that flow in a conductor are already there. A similar example is a garden hose that is already filled with water. The instant you turn on the faucet, water starts to come out the other end. The quantity of water that goes through the hose depends upon the pressure applied.

Measuring Electrical Current

THE TERMS FOR ELECTRICAL PRESSURE are *potential* and *electromotive force* (often abbreviated *emf*). A high *emf* is like the high water pressure at the bottom of a high dam. A low *emf* is like the low water pres-



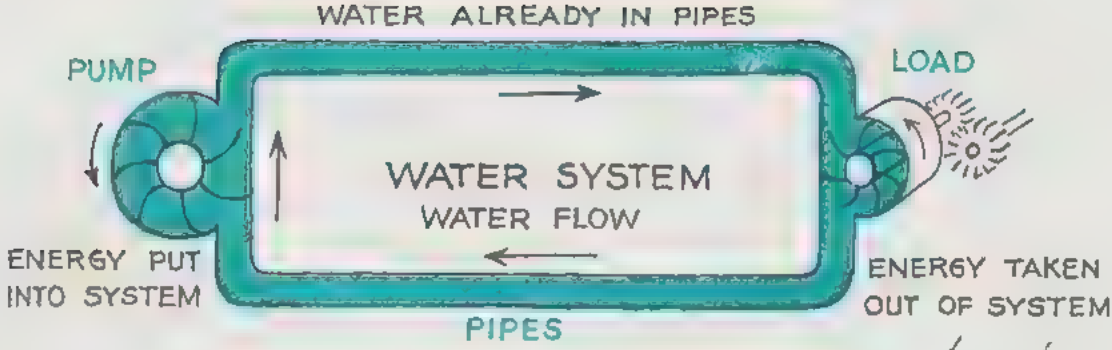
POINT Ⓐ IS AT HIGHER POTENTIAL THAN Ⓑ AND THE SAME AS Ⓒ

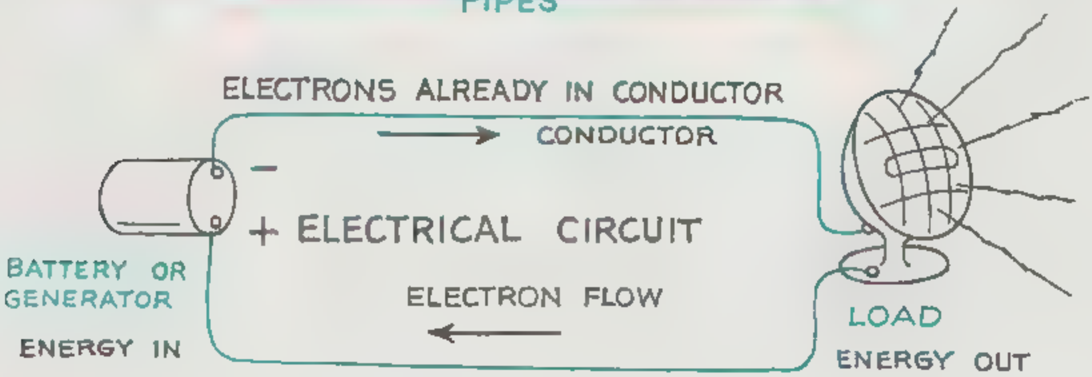
sure at the bottom of a shallow lake. But *emf* is a relative consideration. There can be none between two bodies if both are at the same electrical pressure.

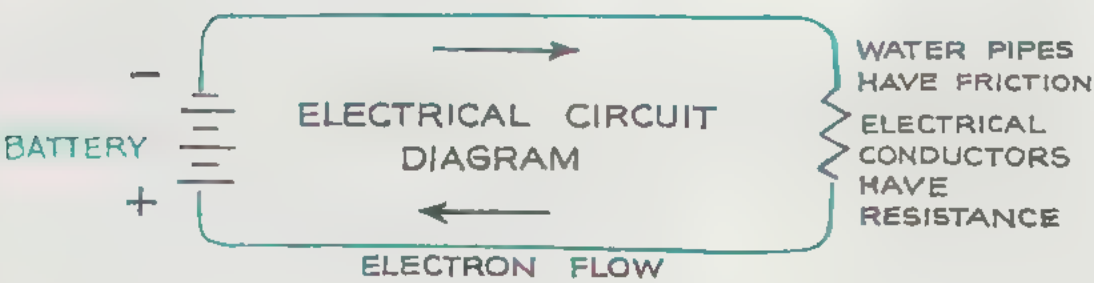
In an electrical situation the supply of electrons that comes out of one end of a wire must be replenished at the other end if a current is to flow. This is accomplished by the use of a closed loop, or *circuit*. The simplest form of circuit can be made with a battery and a piece of wire. With the wire connected to each side, or *terminal,* of the battery, current will flow through the wire and through the battery. The battery is the source of electromotive force. You were the "battery" in the circle of boys. This simple circuit is like a circle of water pipe with a pump in the circle. As

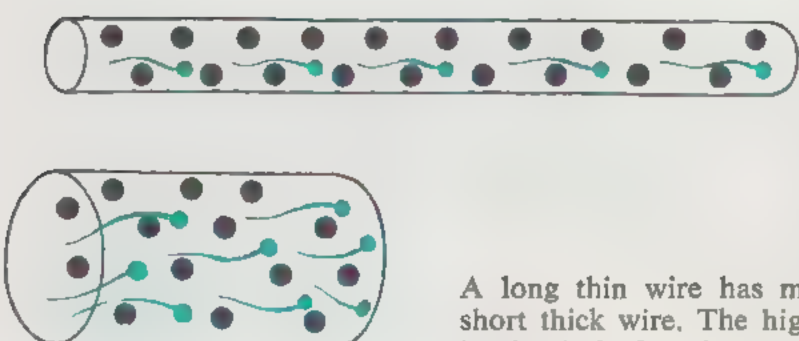
Inside the British atomic power plant at Calder Hall. This is the turbine room, with each unit painted a different hue for rapid identification in case of failure.

4. TURBINE ROOM

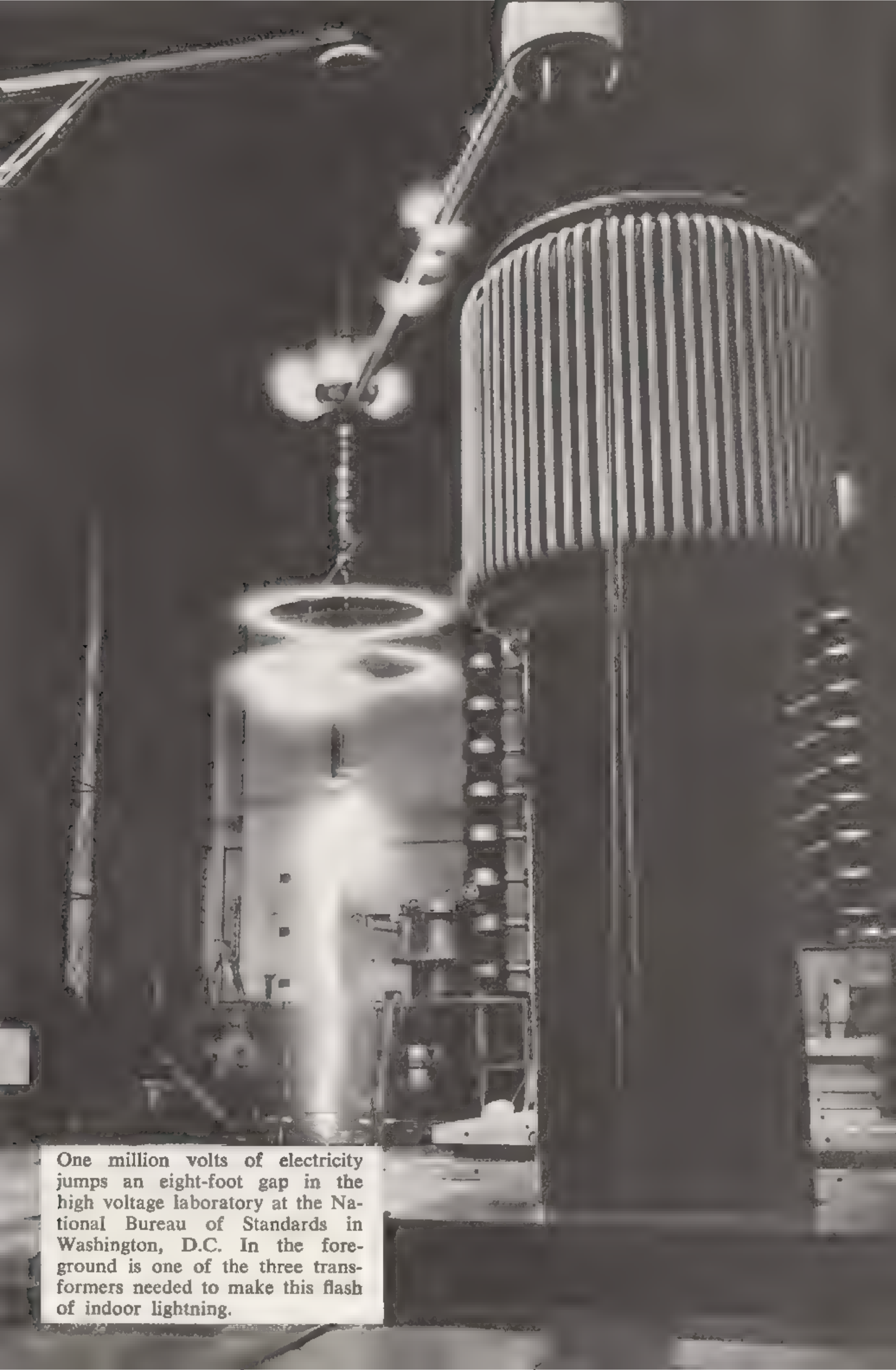








A long thin wire has more resistance than a short thick wire. The higher the resistance, the harder it is for electrons to pass through.



One million volts of electricity jumps an eight-foot gap in the high voltage laboratory at the National Bureau of Standards in Washington, D.C. In the foreground is one of the three transformers needed to make this flash of indoor lightning.

long as the pump is running, the water circulates. If the pump is turned off, or disconnected, the water stops circulating. Any source of *emf* such as a battery or generator is, in effect, an electrical pump.

The friction in the water pipes that will make the circulation stop when the pump is turned off is similar to the friction in an electrical conductor. Electrical friction is called *resistance.*

If you have a certain size of hose, you can push more water through it provided you increase the pressure. Or if you have only a certain amount of pressure available you can get more water to flow through if you have a bigger hose with less friction. A mathematical equation describing these relationships in a simple electrical circuit was devised by a German physicist in 1827. Now called *Ohm's Law,* in honor of Georg Simon Ohm, this simple equation states that E=I times R. Or I=E divided by R. E is the electromotive force measured in volts, R is the resistance of the circuit in ohms, and I is the current. From I=E divided by R, Ohm's Law shows that a higher voltage or lower resistance results in a greater amount of current flow.

Water flow in a pipe is measured in gallons per hour. Electrical current could be measured in electrons per second, but an electron is so small that in just one second an astronomical number of electrons will pass through a circuit. Named in honor of the French mathematician André Ampère, the unit of measure for current is the *ampere.* One ampere is equal to 6.242×10^{18} or 6,242,000,000,000,000,000 electrons flowing per second past a given point.

Electricity from Chemistry

METALS ARE FULL OF FREE ELECTRONS. In some metals, the molecules give up electrons more easily than in other metals. Zinc is one metal which gives up its electrons freely. Copper retains its electrons more firmly.

When copper and zinc are placed in contact, something happens. Electrons pass from the zinc to the copper. The copper, we say, builds up a negative charge; it has an excess of electrons. The zinc acquires a positive charge; it has a shortage of electrons.

The activity is very small in dry metals. But if you should dip a strip of zinc and a strip of copper into a container filled with a liquid such as a salt solution (an electrolyte), the movement of electrons is much more rapid—or rather, more electrons move.

The two metals do not have to be copper and zinc. Any two dissimilar metals will produce the same effect. In fact, if the dentist has put fillings in your teeth containing dissimilar metals, you can readily notice an electrical action. You can not only detect a "metallic" taste in your mouth, but you may even feel a sharp twinge of pain caused by an electric current.

3. GENERATORS

A technician inspects one of the generators in the power plant on the Shannon River at Ardnacrusha in Ireland. Notice the pilot bulb surmounting the second generator, a feature typical of this design.

The "cell" which produces electric current by strips of dissimilar metals dipped into an electrolyte is called a *voltaic cell,* because it was first devised by Allesandro Volta about 1800. It is a means for using a chemical reaction to produce electricity.

When a wire is used to connect two plates of a voltaic cell, a circuit is completed. It is safe to touch the metal strips or the wire where the current is flowing because the electricity produced is of low voltage and current. But the current is continuous—unlike the tremendous power of a stroke of lightning which is over in a flash, long before you can hear the thunder it produces.

As fast as the electrons flow through the wire from the copper to the zinc, they are extracted from that part of the copper in the solution and new electrons are added to the zinc in the solution, so that the flow is kept up. It goes on and on so long as the chemical action continues.

The Dry Cell

THE VOLTAIC CELL is very useful in the laboratory, but for everyday use, to provide current for some doorbells or most flashlights, it is more convenient to use a dry cell.

The dry cell is actually an ammonium chloride cell, in which the liquid has been replaced by a moist paste of ammonium chloride and manganese dioxide. The container is of zinc, and forms the negative pole. The positive pole is a carbon rod in the middle of the container. The space between carbon and zinc is filled with the paste. You do not freshen up your dry cell by replacing the chemical or the zinc container. Since it is inexpensive, you just throw it away when it is exhausted.

The Storage Battery

THE BATTERY WHICH FURNISHES THE CURRENT for starting your automobile engine is called a storage battery. It does not store electricity, however. Like the voltaic cell, the storage battery produces electricity from chemical action. What it stores is the potential energy of plates of dissimilar metals and the chemical electrolyte.

The most commonly used storage battery consists originally of two lead plates immersed in a dilute solution of sulphuric acid. When the lead strips are connected to the terminals of a battery, current passes through the storage battery. Bubbles of gas will form at both plates. One plate remains unchanged by the chemical action but the other becomes covered with a brown substance. This is peroxide of lead. Now the plates are no longer the same. One is lead and the other peroxide of lead. As your mechanic would say, your battery is charged.

The battery will furnish current until the acid is consumed and the peroxide of lead coating on the positive plate is given up. When this happens your battery is "dead". It can be restored, however, by another recharging. The chemical process can go on, be reversed and repeated many times.

Now: Fuel Cells

WE ARE STARTING TO HEAR MORE and more about fuel cells as a source of energy to provide light, heat and air conditioning for the

HOW MUCH WORK DO YOU GET
FROM A KILOWATT-HOUR OF ELECTRICITY?

One kilowatt-hour will run the following electrical appliances for the length of time indicated:

Clock	3 weeks	Washing Machine	3½ hours
Sewing Machine	13 hours	Hair dryer	3½ hours
Radio	13 hours	Iron	1 hour
Blanket	6 hours	Toaster	55 minutes
Oil-burner motor	4 hours	Dishwasher	50 minutes
Refrigerator	4 hours	Air conditioner (window type)	46 minutes
Television	4 hours	Clothes dryer	13 minutes
Freezer	3½ hours	Range	5 minutes

home, and power for the family car. They have already proved their reliability in space flights and in limited experiments here on earth.

There is nothing really new about fuel cells, if you remember that the first operational version was built in 1839 by Sir William Grove. Fuel cells are a kind of chemical battery. But while both dry cells and storage batteries generate current in cells through a chemical reaction, they operate efficiently only when current is demanded intermittently. One great advantage of a fuel cell is that it continuously provides uninterrupted electrical energy as long as current is demanded—and until the external fuel supply is exhausted.

The fuel cell's greatest advantage is its extremely high efficiency when compared with other methods of power generation, theoretically as high as eighty per cent. Fuel cells have additional advantages that compensate for their expense. They are noiseless and give off relatively little heat or noxious fumes. In effect they are batteries that do not wear out, or do not need recharging and are of little weight. For example: while the fuel cells used for power in the Gemini spacecraft weighed less than one

astronaut, a conventional battery powerful enough to do the same job would weigh a ton. Fuel cells come in many varieties. The simplest is the hydrogen-oxygen cell containing two electrodes and one electrolyte. Gaseous hydrogen fuel is fed through the one porous electrode, and gaseous oxygen fuel is fed through the other. The hydrogen and oxygen react to produce water and electric power.

Electricians are at work here on the complicated wiring of a big generator in Antwerp, Belgium.

5. ELECTRIC MOTOR

Hydrogen can be replaced as a fuel by such hydrocarbons as propane and butane, by carbon monoxide or zinc, among other chemicals. Oxygen from pure air can be used as the other fuel, rather than pure oxygen from a tank.

Characteristics such as operating temperature, pressure, type of electrode and the kind of electrolyte, may also vary. The fuel cells used in Gemini operated on hydrogen and oxygen with an ion-exchange membrane as the electrolyte, having an electrical output of 2,000 watts. The

cells used in Apollo had all-metal electrodes and an alkaline electrolyte. An experimental fuel cell system using coal as a fuel has been developed, and the power generated directly from the powdered coal has operated a television set. This research is aimed at the development of a practical, large-scale coal-burning fuel cell system for electric power generation.

From Electricity to Heat

THE PURPOSE OF ANY ELECTRICAL CIRCUIT is to convert electrical energy into some other kind of useful energy, such as heat, light or motion. Energy put in one place in a circuit pushes the electrons through the circuit. They in turn push on something else somewhere else in the circuit that puts the energy to a useful purpose.

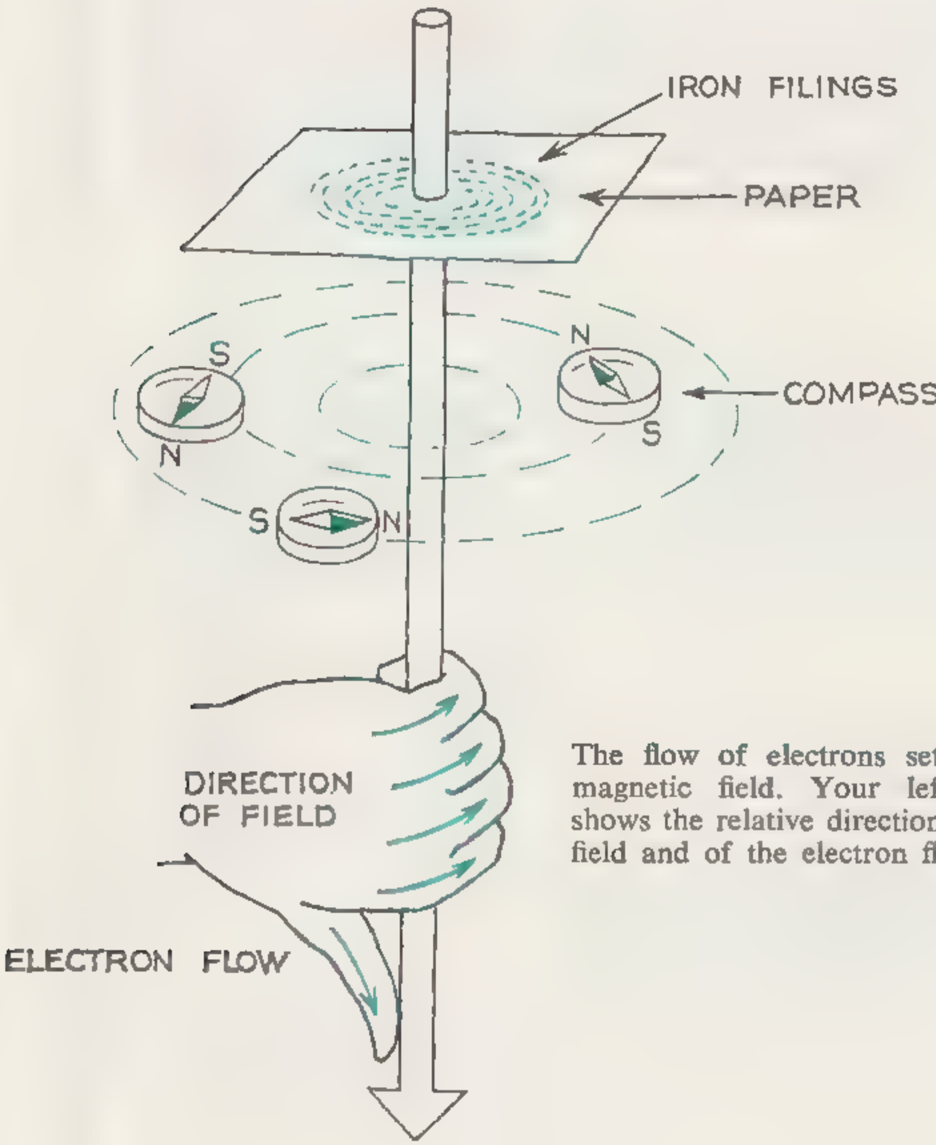
When electrons flow through a conductor they are moving through a maze of atoms. As the electrons move, they collide frequently with other electrons. This slows them down, they lose some of their energy and heat is released. This heating is similar to that which results from beating a piece of metal with a hammer.

It is understandable that a thick wire with a few electrons or small currents flowing through it doesn't get as hot as a thin wire with a large current trying to get through. Many household appliances and industrial devices make good use of the principle that electrical current creates heat.

Bread is turned into a golden toast by heat. Inside your toaster are filaments of high-resistance conductors that get red-hot when current flows through them. These heating elements, like the coils of an electric stove or hot plate, are made of materials that won't melt at high temperatures. Even the common light bulb depends on electrical heating. A fine, high-resistance filament inside the bulb gets so hot that it glows brilliantly. It doesn't melt at this extreme temperature because it is made of a tungsten alloy. Tungsten has a melting point of nearly 6,100° F. It doesn't burn up because the air in the bulb has been replaced with an inert gas that won't support combustion.

But heating is not always a good thing. Any size of conductor has some resistance, and the passage of a current, regardless of amount, will create some heat, which gets wasted or is dissipated into the surrounding air. In a long wire, such as a power transmission line that runs for many miles, this heat loss is appreciable—and expensive. James P. Joule showed that the heat generated in a conductor is proportional to the

resistance multiplied by the square of the current. If the current is doubled, the amount of heating is increased to four times as much. If the current is tripled, the heating is increased by nine times. For this reason most long-distance transmission lines carry comparatively little current. But since the power transmitted is equal to the current times the voltage, a high voltage is needed. Ten amperes at 200,000 volts gives the same amount of power as 10,000 amperes at 200 volts. The power loss due to heating ($I^2 \times R$) is one million times as great at 10,000 amperes as it is at ten amperes if the same wires are used.

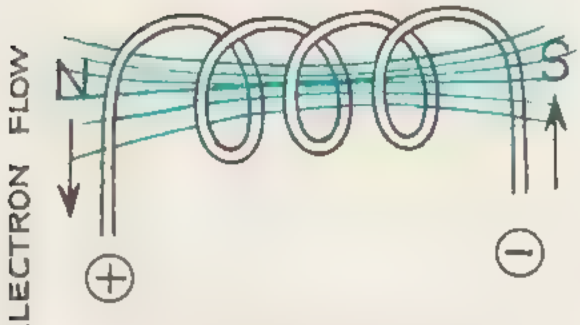


The flow of electrons sets up a magnetic field. Your left hand shows the relative direction of this field and of the electron flow.

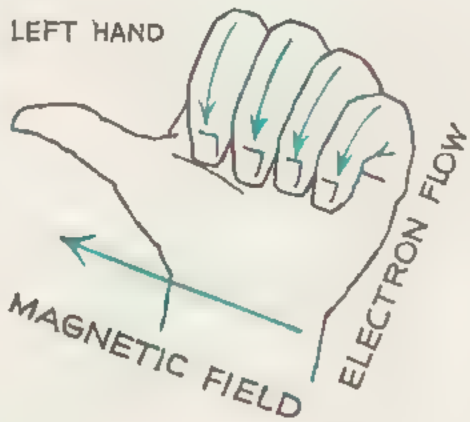
Oersted's Magnetic Effect

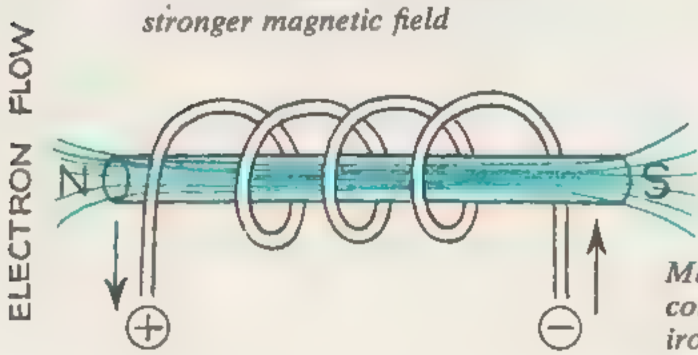
THE MAGNETIC EFFECTS of current flow were discovered by a Danish scientist in 1820. Hans Christian Oersted brought a compass near a wire through which current was flowing and noticed that the compass needle, which was parallel to the wire, swung around. With the wire vertical he passed the compass around it. The compass point ignored the magnetic north pole of the earth and pointed in the same direction the compass was being moved. When Oersted turned off the current the compass returned to normal and pointed, as a good compass should, to the north pole. When the current in the wire was reversed, the compass still traced the path of the circle, but its pointer faced the other way. Oersted had discovered a most important phenomenon: the flow of electrons in a conductor sets up a magnetic effect around it.

An exact rule for predicting compass needle behavior close to a flowing current was formulated by the French mathematician, André Ampère. Among other achievements, Ampère had at one time written a book on the subject of the mathematics of gambling. Within just seven days of



Magnetic fields of all turns in a coil combine to make a stronger magnetic field





Magnetic "lines" of force concentrate in the soft iron core of an electro-magnet

Science Bulletin

Prepared by SCIENCE SERVICE

UNDERWATER WINDMILLS

Large, slow underwater machines like windmills could be a promising source of fuel-free, nonpolluting electric power in the Gulf Stream off the Miami coast, suggests John R. Apel of the National Oceanic and Atmospheric Administration's laboratory on Virginia Key, Florida.

An optimum spot would be the Straits of Florida which pass between Miami and the island of Bimini, where the flow of the current is channeled and steady, varying by only about twenty per cent above or below normal, reports Apel together with William S. von Arx and Harris B. Stewart, Jr., of the Woods Hole Oceanographic Institution.

About 0.8 kilowatts of power per square meter could be obtained from the upper levels of the current, the researchers estimate. This would be an improvement over the 0.22 kilowatts available from sunlight over Miami, says Apel, which would be reduced another seventy-five per cent by the inefficiency of solar cells used to collect the sun's energy.

SHARKS' ELECTRIC SENSORY DETECTORS

The ampullae of Lorenzini are tiny bladders found in the skin of all sharks and rays. They are connected to

surface pores by long canals. Because these small sacs are full of nerve endings, scientists believed them to be some sort of sensory receptor. But none knew what they were sensitive to.

In 1971 biophysicist A. J. Kalmijn reported that sharks use the ampullae to detect prey buried in the sand. He found that the ampullae are excited by the electric field emitted by buried fish. In experiments, a shark detected and aimed attacks at a buried fish, even when it was covered by an agar plate that prevents mechanical, visual or chemical cues but allows an electric current to pass through. Agar is a gelatin-like substance obtained from seaweed. The shark also attacked buried electrodes carrying a current equivalent to that of a fish.

Theodore H. Bullock, a collaborator of Kalmijn at the Scripps Institution of Oceanography, has been studying electroreceptors since 1959. He reports that sharks, catfish and electric fish use electroreceptors in object detection and social communication.

Nearly all animals, including humans, emit into seawater direct-current electric fields as a result of different electric potentials between body fluids and ocean and between different parts of the body. Sharks, sensitive to the electrical equivalent of one flashlight cell at 1,500 kilometers, are sensitive to all of these fields. A wound, for example, can double the voltage gradient from a person in seawater. A shark can detect this.

In addition to such bioelectric fields, there is a world of inanimate fields induced by the motion of water, bodies of ore, earthquakes and atmospheric disturbances. During and prior to earthquakes in Japan, certain catfish there have shown behavior which, says Bullock, "is evidently dependent on changes in the electric current of the earth."

The long canals of the ampullae, he explains, enable certain fish to sample electric fields at two widely spaced points. With this ability, he suggests, they not only detect prey but may be able to use electric fields as navigational aids and to communicate with each other.

Bullock admits that the studies are in their infancy but says, "Like many basic questions of neurobiology, answers or clues from lower species may help us to understand the brains of higher forms."

MOVING PARALYZED MUSCLES

Electrical impulses can move paralyzed muscles. NASA has been working for several years now to perfect a system that can be used by paralytics. Working with Rancho Los Amigos Hospital in Downey, California, the agency has now helped develop a connector that applies small electrical currents from an outside power source through tiny terminals embedded in the patient's skin.

Some of the technology was already in experimental use but there were problems, which NASA has helped solve.

Tiny platinum wires attached to small pads on certain nerve endings are brought up to the surface skin. But the connectors attached to make contact with the metal conductors in the implant embedded in the skin would often injure the skin if there were a sudden movement.

So Ray Cerrato's group at the Kennedy Space Center developed a small, lightweight, inexpensive connector that would make good electrical contact but that would be easily dislodged in case of sudden movement, thus avoiding injury.

VIDEO TAPE RECORDINGS OF LIGHTNING

Scientists in New Mexico studying lightning have found that television video tape is proving to be a useful tool for recording lightning flashes, especially in daytime.

Recordings by William P. Winn and colleagues of 110 lightning flashes during the summer of 1972 revealed that for flashes with two or more channels to the ground, the channels occurred more nearly simultaneously for flashes to the mountaintop than for flashes to the surrounding plains.

LUMINESCENT WHITE BLOOD CELL

It is known that lower organisms such as sponges, jellyfish, clams, shrimp, fireflies and glowworms luminesce or glow. This luminescence is created by the excitation of electrons by certain chemical reactions within the organism. The energy is lost as light. The light produced causes the organism to glow.

Now it has been demonstrated, by Robert C. Allen, Richard Steele and Rune Stjernholm of Tulane University, that luminescence also occurs in mammals.

They have found that the human white blood cell luminesces when it makes a chemical to destroy bacteria. The electronically excited microbicidal agent then engages in bacterial destruction—perhaps by oxidizing target bacteria (removing electrons from them).

THE LATEST ON ROBOTS

Several projects throughout the world are aimed at teaching a robot to assemble machines from a pile of parts.

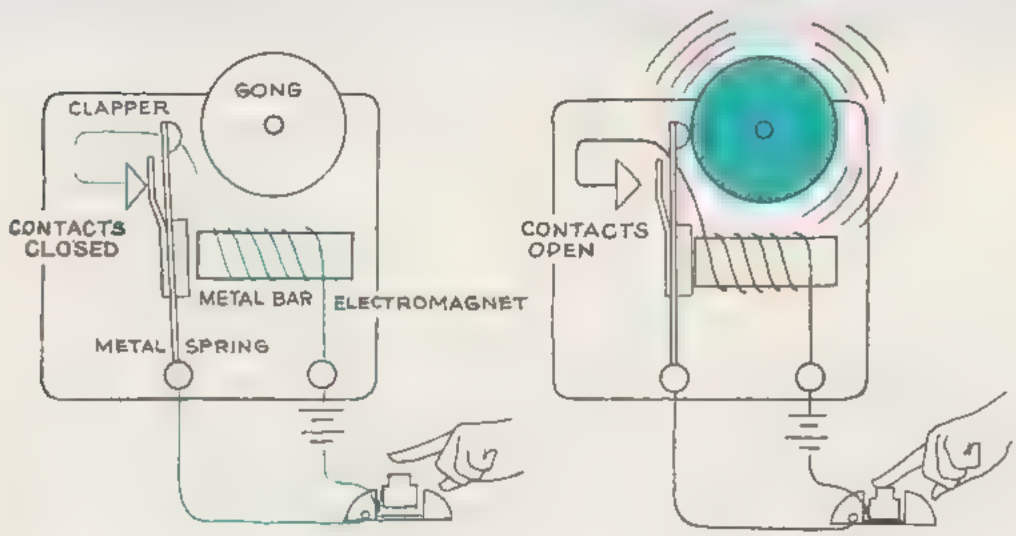
In Japan a robot follows instructions given in the form of line diagrams of the components. At the Massachusetts Institute of Technology a robot learns to copy a pre-assembled pile of blocks. At Stanford, preprogrammed hand manipulations control the automatic assembly of an air pump.

One of the most versatile approaches is that taken by the Department of Machine Intelligence at the University of Edingburgh. There a computer learns about a group of objects firsthand by picking them up with a mechanical hand, and looking at them through a television system and finally assembling them into a structure, all under the tutelage of a human operator. After a while, the computer "catches on" and can finally be left by the operator, busily putting simple toys together like a preoccupied child.

reading about Oersted's experiment, Ampère prepared and delivered his first paper showing the mathematics for predicting exact relationships between electricity and magnetism. This and later papers showed that the strength of this magnetic effect depended upon how much current was flowing. The region of magnetic effect he called an *electromagnetic field* or simply a *magnetic field*. He also found that when a current-carrying wire is wound like a coil, the magnetic fields of all the turns of the wire combine into a much stronger field. The strength of the total field depends directly upon the number of turns.

Finding Practical Uses

THE MAGNETIC EFFECT was put to practical use by William Sturgeon, who discovered in 1825 that an ordinary bar of iron can be made into a magnet by using electricity. If a bar is wrapped with turns of wire, and current is passed through the wire, the bar becomes a magnet and behaves like a natural magnet as long as the current is flowing. The



LEFT: Button up—the circuit is open. The spring keeps the metal bar away from the electromagnet and the clapper away from the gong.

RIGHT: Button down—the circuit is closed. The electromagnet attracts the metal bar, the clapper strikes the gong, and the circuit is broken at the interrupter contacts. The electromagnet stops pulling at the metal bar and the spring returns the arm to the rest position thereby closing the circuit again. This process is repeated very rapidly for as long as the button is kept pressed down.

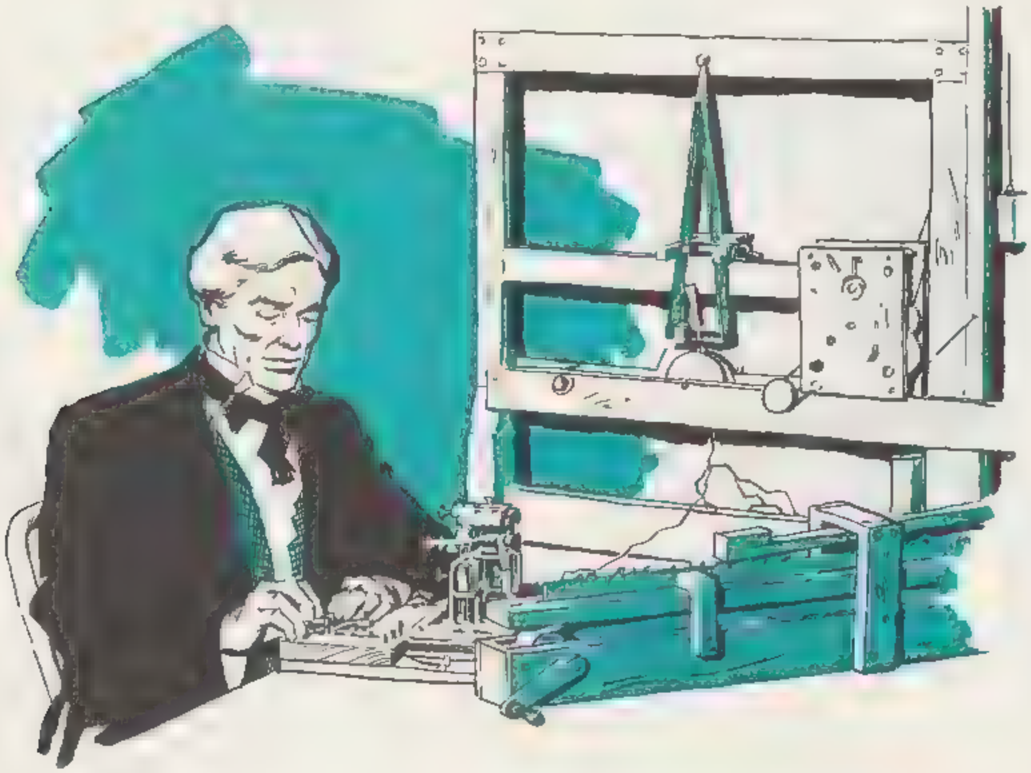
A battery of fifty compact-arc, high-intensity lamps provides striking illumination for an Apollo moonship on its launch pad at Cape Kennedy.

magnetic field of the coil tends to concentrate in the bar and the bar increases the strength of the magnet. The polarity (which end will be north, and which end south) of this "electromagnet" is reversed when the direction of the current is reversed. Sturgeon and Joseph Henry, who duplicated this discovery, had shown the world how to make a magnet that could be turned on and off at will.

Doorbells and Telegraphs

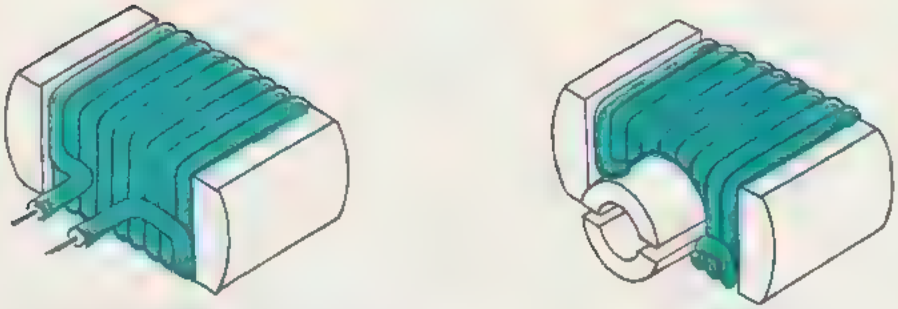
A COMMON APPLICATION of the electromagnet today is the household door chime or gong. A metal bar with a clapper on one end is hinged near an electromagnet. When the doorbell is pushed the circuit

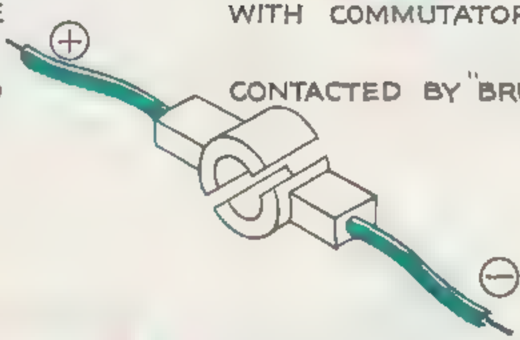
is connected and a current flows through the electromagnet. This draws the bar toward it, making the clapper strike the chime. Ringing bells work on this principle too, but with an additional device called a circuit *interrupter.* When the button is pushed and current flows, the armature moves toward the magnet causing the clapper to hit the gong. But when the armature reaches the magnet, the circuit is broken by the interrupter, the current stops, the magnet loses its power, and a spring pulls the armature back to its original position. This completes the circuit again and the cycle is repeated. The armature with its clapper will move back and forth as long as the button is held down.



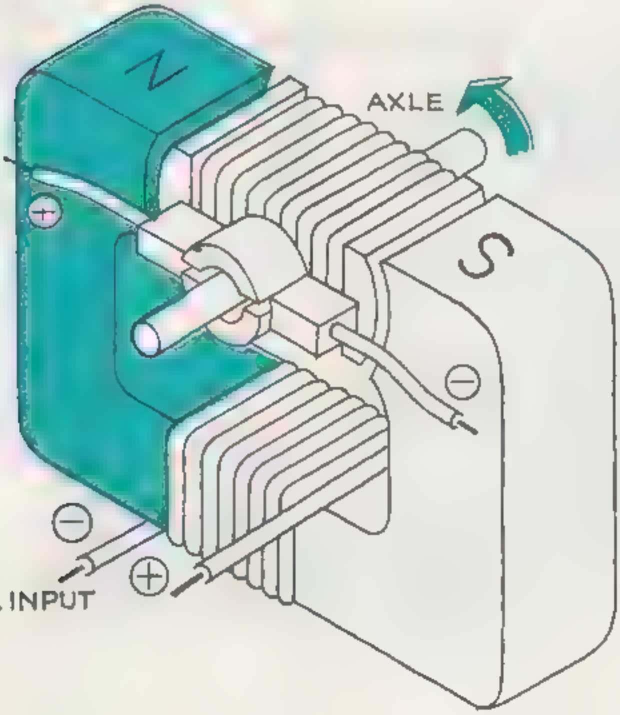
Samuel Morse at the sending key of his electric telegraph in 1837.

In the field of communications the electromagnet saw early service as part of the telegraph. Samuel F. B. Morse experimented with electromagnets in 1836 and the first telegraph was soon put into service between Washington and Baltimore. This historic message "What hath God wrought" was transmitted in a code of dots and dashes by transmitters and sounders using electromagnets. The sounder was essentially an electro-





The armature is free to spin on its axle between the poles of an electromagnet



The metal brushes stand still but are rubbed by the commutator segment as the armature rotates

The polarity of the field magnet remains the same; as the armature rotates, the commutator changes the direction of the electron flow and therefore the polarity of the armature at exactly the right moment for rotation of armature to continue.

magnet whose moving armature made audible clicks when actuated by a transmitter miles away.

Big Step: The Electric Motor

PERHAPS THE MOST IMPORTANT STEP in electromagnetism was the creation of motors and generators. The electric motor converts electrical energy into rotary motion. The generator converts the energy of rotary motion into electricity.

The first practical electric motor was developed by Thomas Davenport in 1834, three years after Joseph Henry had demonstrated the motor principle. The basic elements of a motor are a strong magnetic field and a group of conductors that can move in that field. A simple motor is composed of a *field magnet* and an electromagnet on an axle called the *armature* or *rotor*. The field magnet is a big electromagnet bent into such a shape that its poles face each other with just enough space in between to permit the armature to rotate. The armature, usually made of iron, is wrapped with turns of wire. When a steady current is passed through the wire, the armature becomes a magnet with a north pole and a south pole.

The armature is fitted with a device called a *commutator,* against which metal or graphite *brushes* rub. The brushes carry current to the armature without tangling the wires while the armature rotates. The commutator is divided into sections so that each time the armature rotates halfway around, the connections (and therefore the polarity of the armature) are reversed. The polarity of the field magnet remains the same at all times. When current flows in the rotor the north pole of the armature is attracted to the south pole of the field magnet. This makes the armature turn. Just as the unlike poles get near each other the current is disconnected by the commutator. The armature coasts until the commutator is in the position where the brushes again contact the conducting sections. But now the connections are opposite from the way they were before. What was the armature south pole is now north pole; so the cycle repeats. The armature keeps turning because its polarity is changed at just the right time by the commutator.

Most modern motors have armatures with many electromagnets and many segmented commutators so that rotary motion is smooth. The heating of an electric motor is caused primarily by the current flowing through it. Some additional heating is due to mechanical friction at the commutator and in the rotor bearings.

Chemical reactions as a source of electric current are satisfactory in the laboratory or even in an automobile. But this source is inadequate and inconvenient when it comes to furnishing the lighting for the homes and offices of a city, or the power for a nation's factories.

Groundwork for the Generator

IT WAS RESEARCH CONDUCTED by Michael Faraday that made it possible to provide electricity on a vast and widespread scale. Michael Faraday was an inquisitive Englishman who started a youthful career as a bookbinder and later became a renowned chemist and physicist. He was

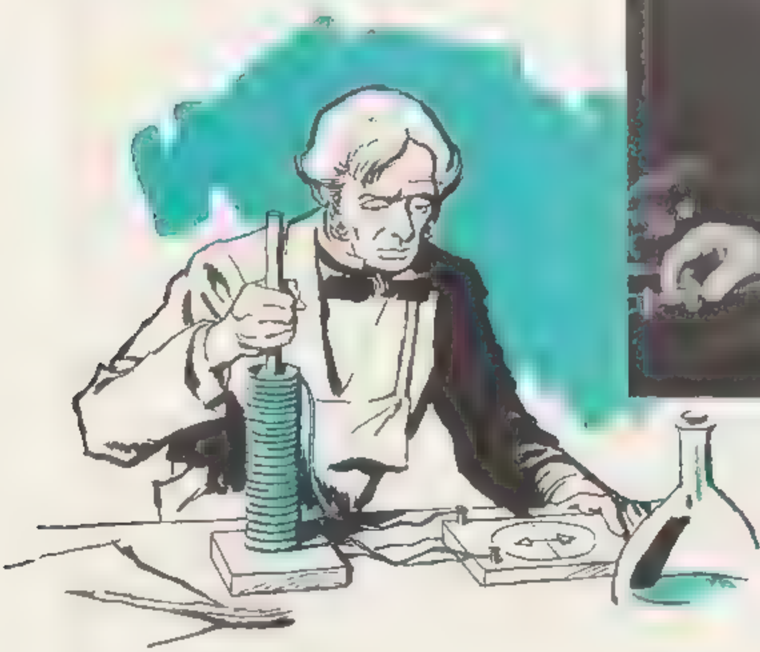
This giant turbine generator is running under full power, while a technician checks the meter panel for a correct output reading.

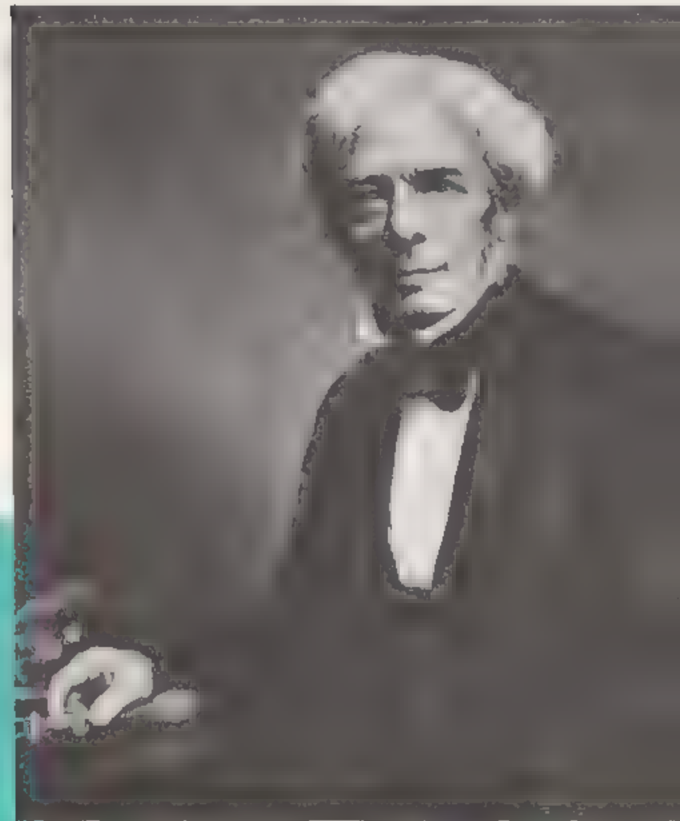
7. ADJUSTING THE LOAD

inspired by the many electrical experiments that had been going on in various parts of the world. As he duplicated Oersted's experiments in 1831, Faraday wondered, "If you can make magnets from current, why can't you make current from magnets?" Faraday's search for the answer to this question laid the foundation for the development of the dynamo and the generator.

Faraday made a coil of wire and passed a magnet through it. He was delighted to discover that a current flowed in the wire. But when he

Michael Faraday moves a magnet up and down in a coil of wire as he duplicates the experiments of Oersted.

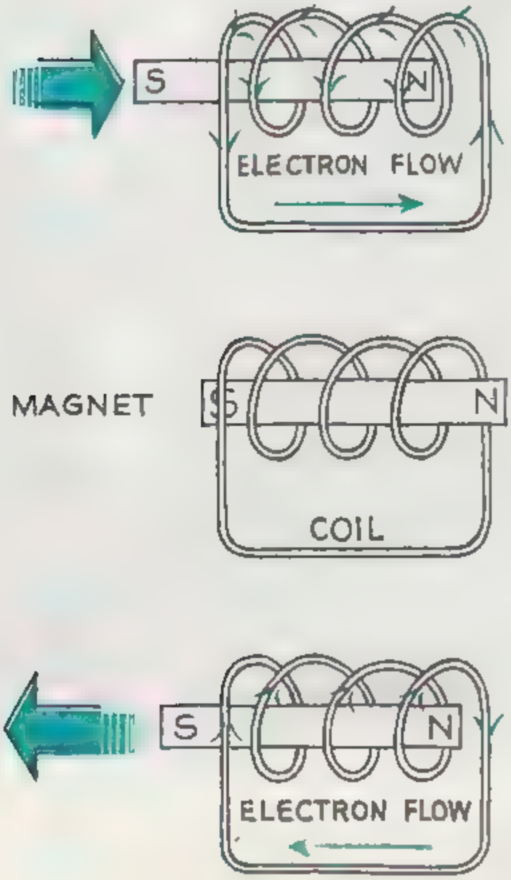




MICHAEL FARADAY

stopped moving the magnet, the current stopped. When he moved the magnet back out of the coil, a current again occurred, but this time in the opposite direction. The same thing happened when the magnet was held still and the coil was moved back and forth. Trying to analyze what was happening, Faraday thought the magnetic field around the magnet must be composed of invisible *lines of force*. He decided that since the current was induced only when the magnet moved, it must be the action of the wire "cutting" through the lines that created an electromotive force. When the lines were being cut an *emf* was induced that caused current to flow in the wire. If the lines were not being cut there was no *emf* and hence no current. Faraday found that the faster the lines were

MOTION BETWEEN CONDUCTORS AND A MAGNETIC FIELD INDUCES AN EMF



Moving a magnet into a coil induces an emf and electrons flow

No electrons flow when the magnet stands still

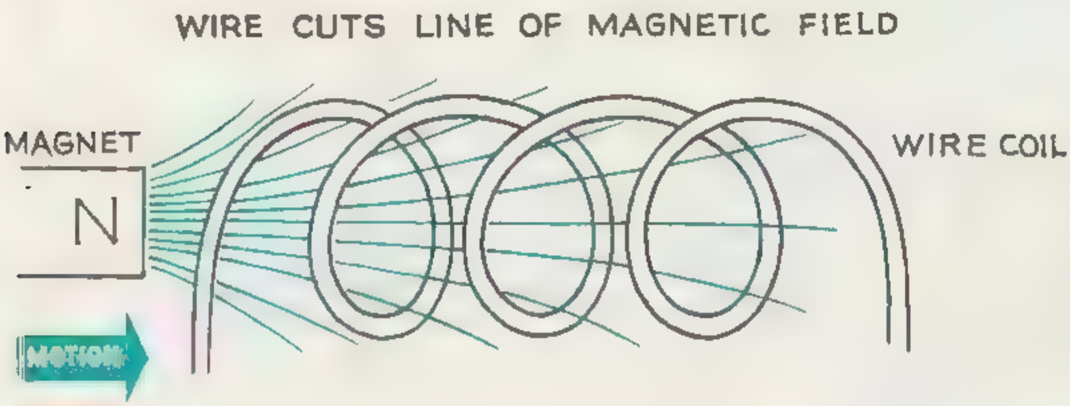
When the magnet is moved out of the coil, the electrons flow in the opposite direction

cut, the greater the *emf* induced. Deduction: A strong magnetic field with more lines of force will create a stronger *emf* than a weak magnet. Faraday would have been surprised if he could have known that 100 years later the generation of most of the world's power would utilize the principles revealed by his work.

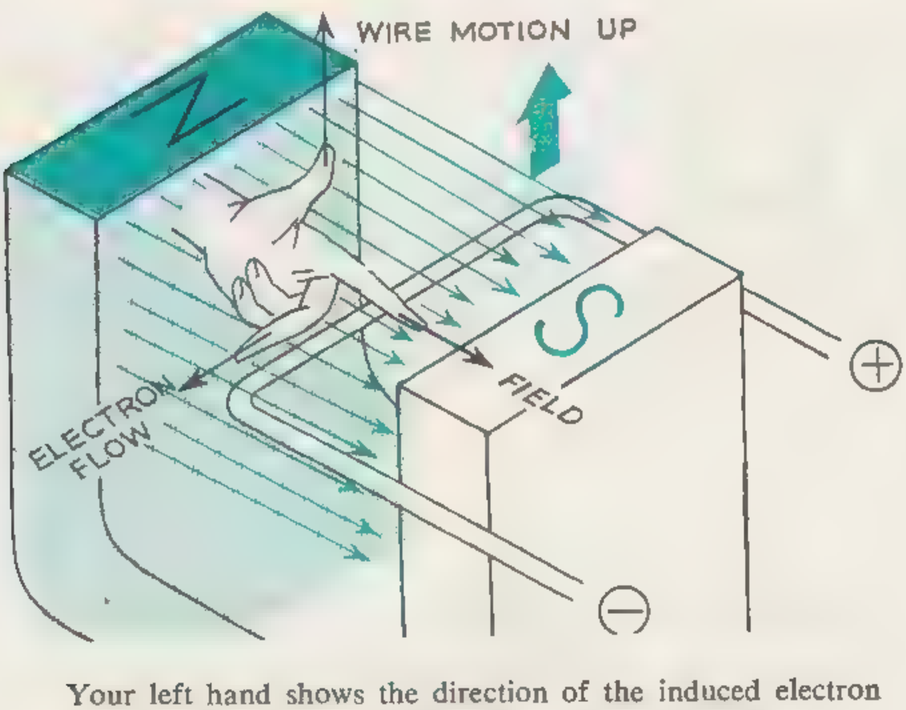
The Man Who Did It

FARADAY'S WORK was carried forward by a scientist with a most unusual name—Hippolyte Pixii—who in 1832 built the first dynamo or electric generator. A clean and quiet device that converts mechanical energy into electricity, the generator can be turned by water wheels,

steam engines or windmills. It is virtually identical to the electric motor, for it has a field magnet and conductors in an armature that rotates in the magnetic field. In essence a generator is just like a motor, but uses mechanical energy to make electricity, instead of vice versa.



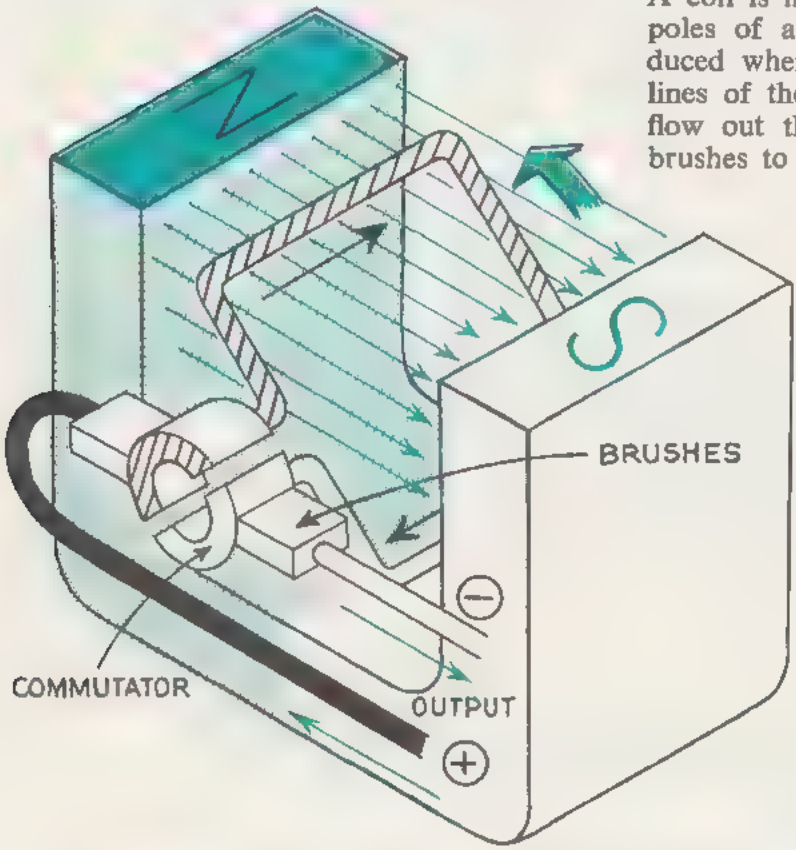
"Cutting" the lines of magnetic force causes electrons to flow. Flowing electrons set up their own magnetic field in opposition to the flow of the magnet.



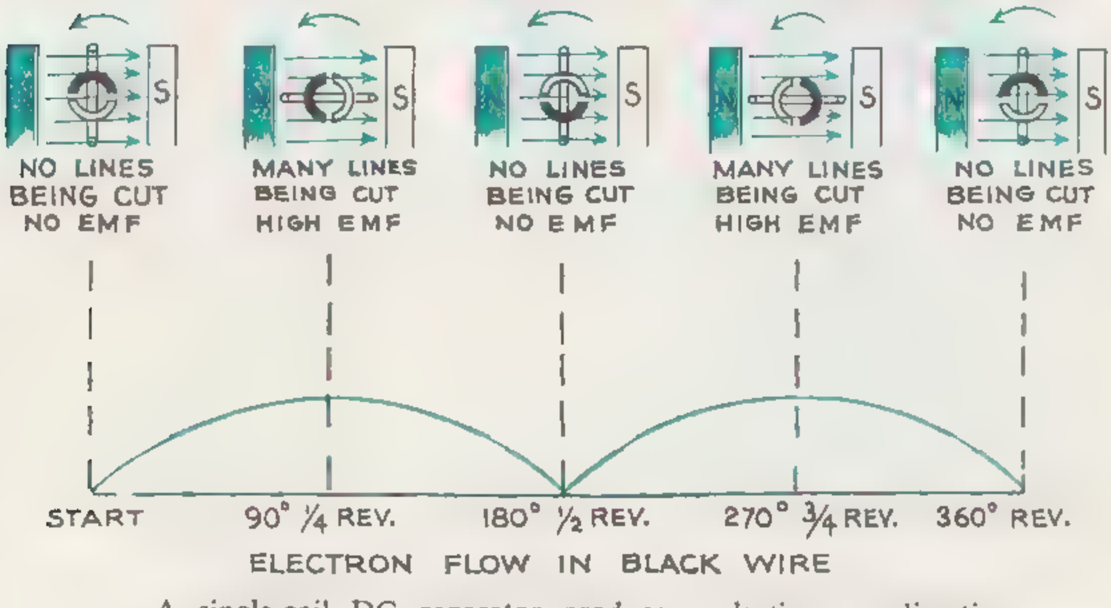
Your left hand shows the direction of the induced electron flow when conductors cut the lines of magnetic force.

DIRECT CURRENT GENERATOR

A coil is made to rotate between the poles of a field magnet. Emf is induced when the coil wires "cut" the lines of the magnetic field. Electrons flow out through the slip rings and brushes to an external circuit.



The hatched half of the armature coil cuts across the lines of magnetic force in one direction while the white half cuts in the other direction.

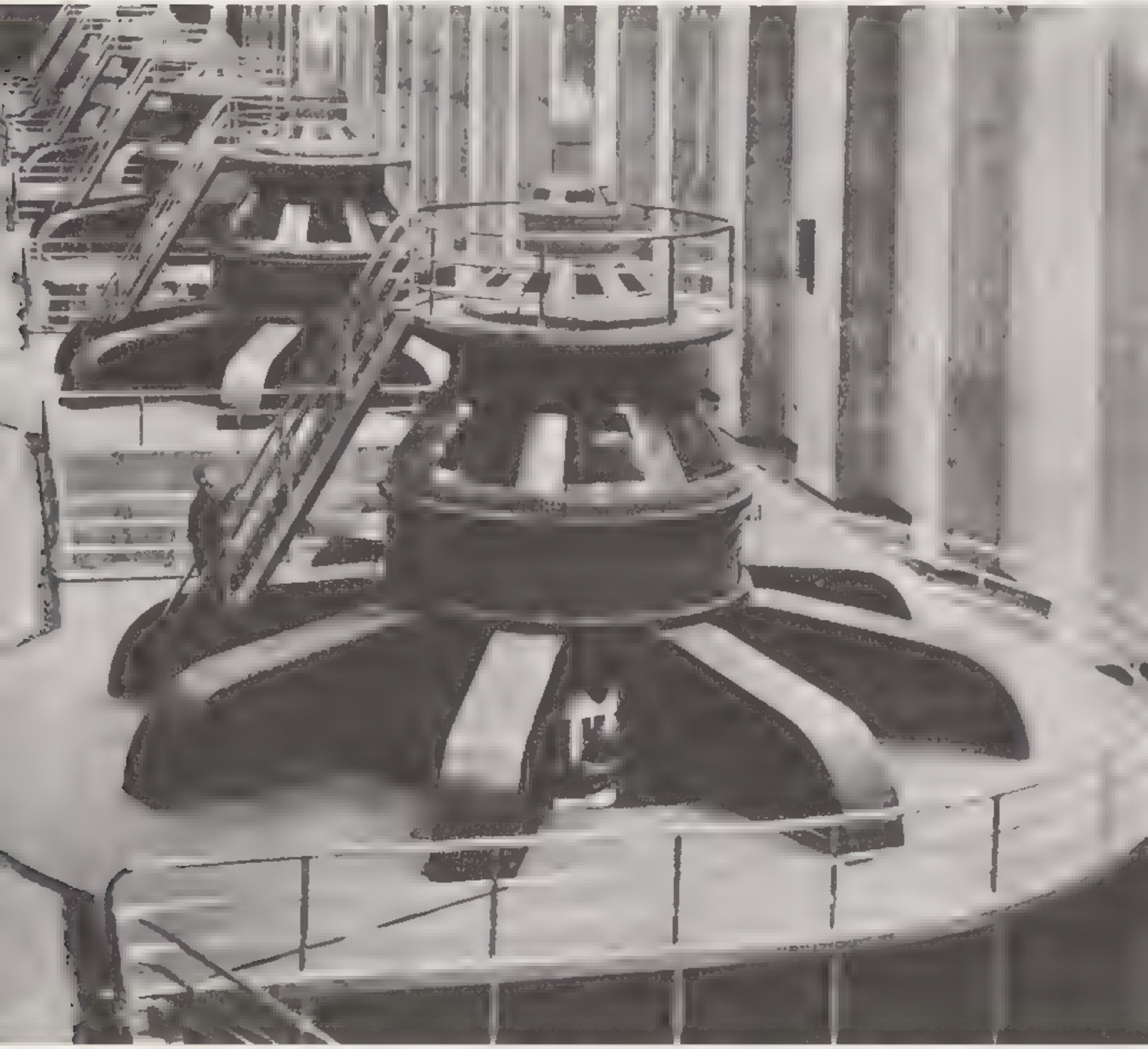


A single-coil DC generator produces pulsating one-direction current; a commutator is used to draw off the current.

Pixii's crude machine uses a permanent magnet for the magnetic field. As the armature is turned with a crank, its wires cut the lines of force of the field magnet. This induces an *emf* in the armature wires which causes a current to flow. When the wires of the armature pass near the poles of the field magnet the greatest possible number of magnetic lines are being cut, so a strong *emf* and large current are produced there. As the armature rotates it gradually leaves this area of strong magnetic

This is the turbine rotor of a modern steam-driven generator. It will spin faster than the speed of sound to turn the shaft of a 50,000-kilowatt generator able to meet electrical power needs of 150,000 people.

effect until, when it is farthest away from the field poles, it generates no current at all. As the armature rotates, the current reaches a peak, decreases to zero, climbs to a peak, decreases to zero, etc. The direction of current on the upstroke is opposite to that on the downstroke. To secure a current that would always flow in the same direction he used a commutator on the armature. A pulsating *direct current* (DC) is the result.



The six electric generators at Hoover Dam are among the biggest in the world.

Suspended from the ceiling by brown and white, heavy-duty insulators, these copper coils are connected to the AC line which is carried in the red conduits.

6. HIGH VOLTAGE

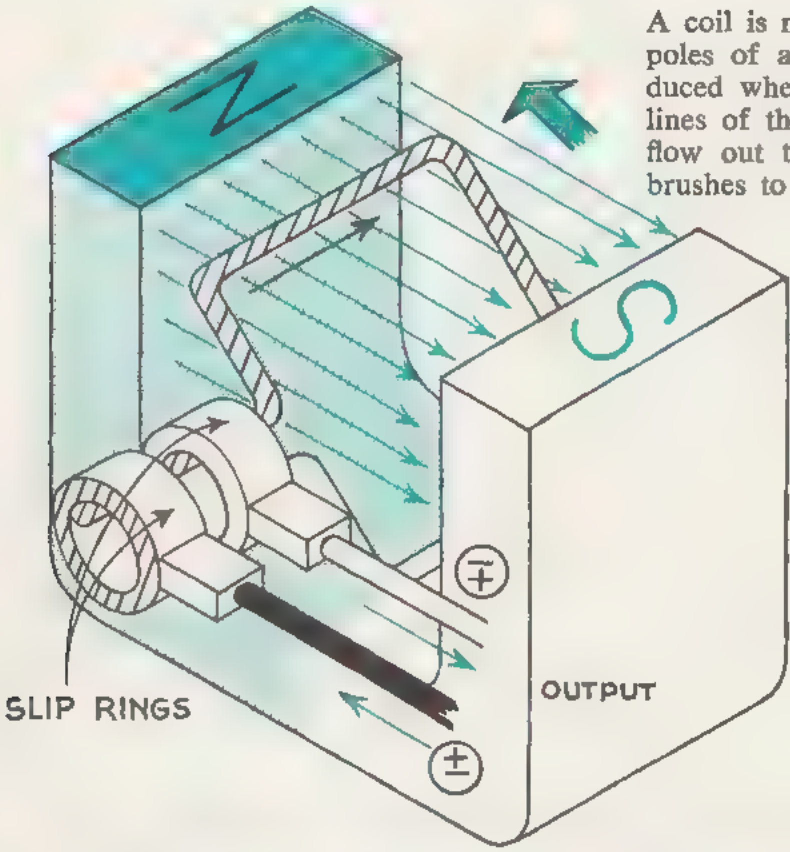
The DC generator of Pixii was improved twice by Charles Wheatstone. In 1845 he used an electromagnet for the field poles instead of a permanent magnet, and in 1857 he demonstrated that the field electromagnets could be sufficiently energized with a small part of the electricity made by the generator itself, with the initial field provided by magnetism left over in the field magnets. Other improvements have been attributed to Zenobe Gramme in 1871, but the first commercially practical model was developed by Thomas Edison, who built a double armature or "bipolar" generator in 1878 that produced a much smoother direct current.

Controversy: AC vs. DC

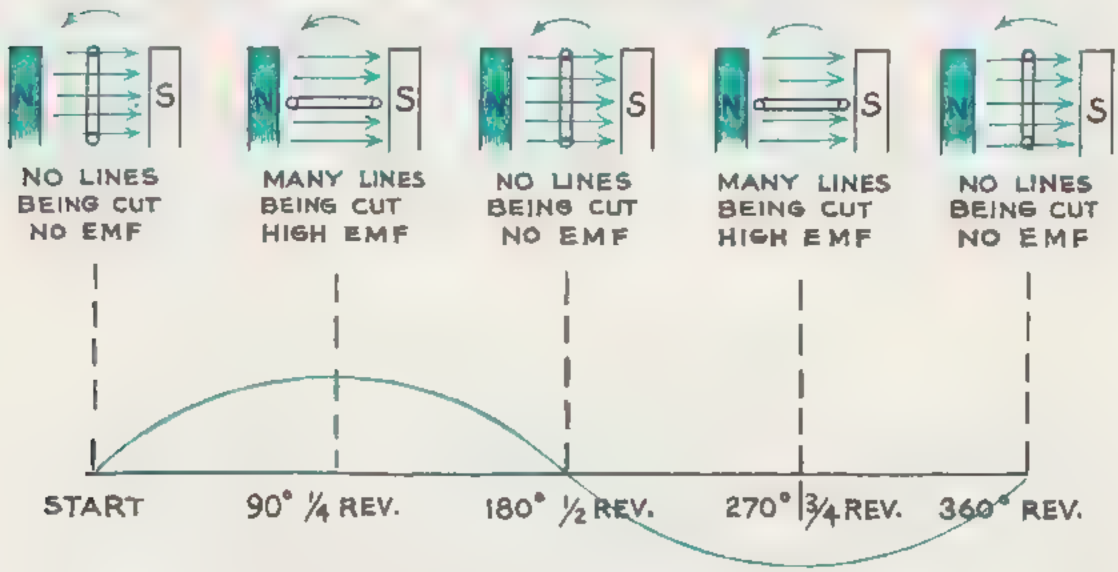
ALTHOUGH MOST ELECTRICAL POWER TODAY is from *alternating current* (AC) rather than DC, alternating current was for a time considered only of academic interest by most electrical inventors. The same year that Edison was building his bipolar DC generator (and predicting that DC would power the world), Elihu Thompson was building a forerunner of today's AC generator. Instead of using a commutator, he used *slip rings,* which are always connected to the same end of the

ALTERNATING CURRENT GENERATOR

A coil is made to rotate between the poles of a field magnet. Emf is induced when the coil wires "cut" the lines of the magnetic field. Electrons flow out through the slip rings and brushes to an external circuit.



The hatched half of the armature coil cuts across the lines of magnetic force in one direction while the white half cuts in the other direction.

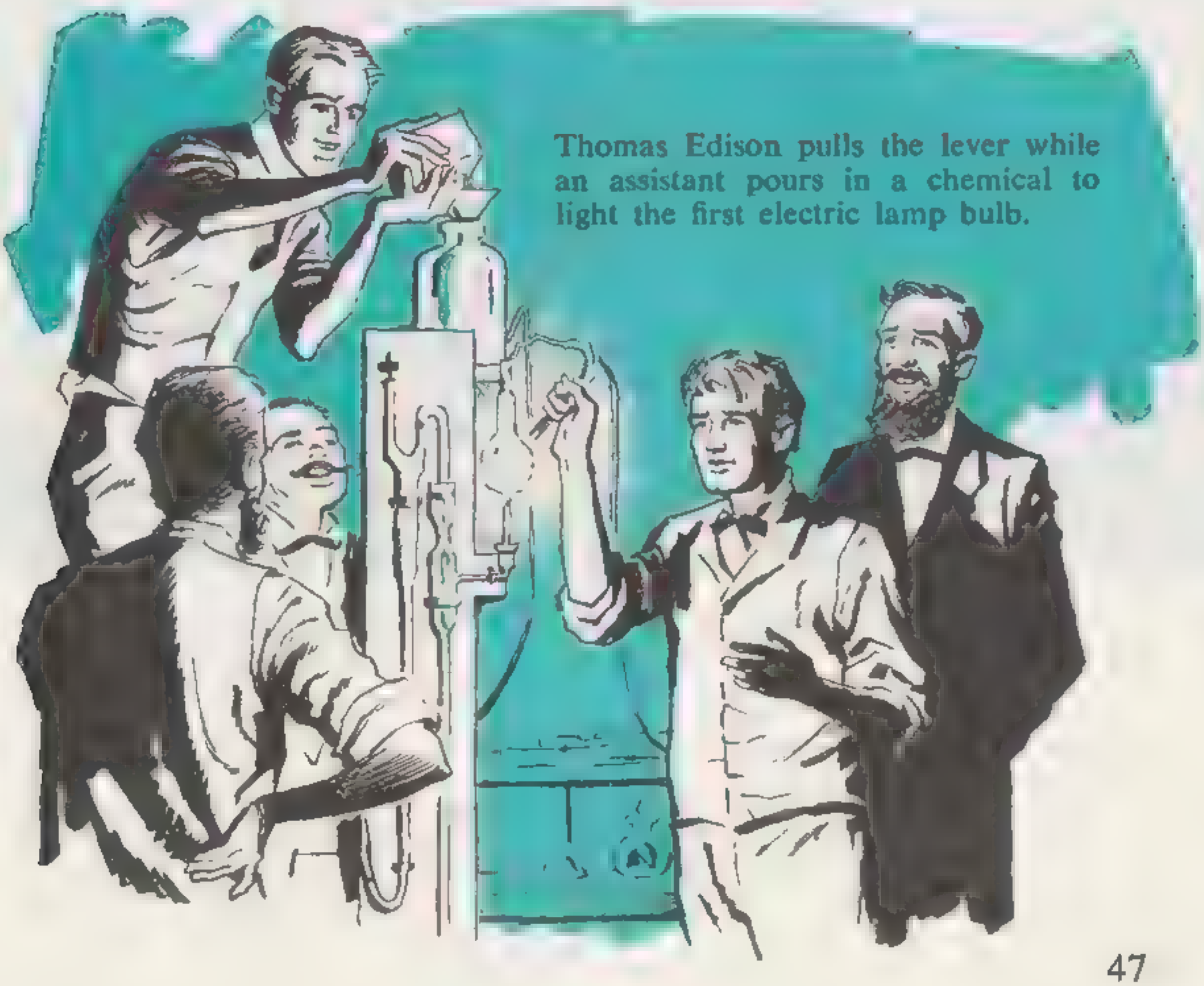


ELECTRON FLOW IN BLACK WIRE

An AC generator has slip rings to allow electrons to flow alternately in and out.

armature coil wire. Brushes riding on the slip rings carry generated current off to a circuit in the same way as brushes on a commutator. The current, however, is different from that drawn off a commutator. It oscillates—it travels first one way and then the other. An induced current in a conductor always flows so that its own magnetism tends to oppose the motion or change that induced it in the first place. As the armature turns between the poles of the field magnet, a south-flowing stream of electrons is created on the northbound half of the spin and a north-flowing stream of electrons is induced on the other half of the cycle. Compare this with the water pump and circle of pipe: first the water is pumped one way and then the other way—in effect going nowhere.

The AC generator received little enthusiasm from most quarters and even Edison thought alternating current was unworthy of development. It wasn't appreciated at the time that alternating current can be put to work in the same ways as direct current. Any current flow, no matter how brief, will create heat because electrons are moving. Any current flow will create a magnetic field around it, even though the polarity of



Thomas Edison pulls the lever while an assistant pours in a chemical to light the first electric lamp bulb.

Thomas A. Edison holding one of his Edison effect lamps, in 1912.

(*Opposite page*) This striking portrait of New York City at sunset shows how much the people of a city depend on electricity.

the field will reverse every time the direction of the current reverses. The general opinion, however, was that if the current goes back and forth the net result must be zero, and therefore worthless. Critics pointed out that alternating current couldn't run a DC motor, the only kind they knew at the time.

The controversy between the relative merits of AC and DC continued among scientists until it was ultimately resolved as an indirect result of the application of the electric light—Edison's own invention, which, ironically, will work equally well with either type of current.

The First Electric Light

THE WORLD OF 1880 had only candles, kerosene and gas lamps for lighting its homes, factories and schools. Sir Humphrey Davy had discovered the electric arc in 1801, and other arc-type devices were tried. But all these tended to be troublesome and expensive to use. The first operating electric lamp was made by a New Englander, Moses G. Farmer, who illuminated his home with experimental bulbs in 1859. But it was Thomas Alva Edison who came up with the first practical incandescent lamp. A thin wire filament enclosed in an evacuated glass envelope glowed brightly when Edison passed current through it. Unlike earlier, unsuccessful lamps, Edison's light glowed for many hours without burning up.

With business acumen that typified his career, Edison almost immediately helped to organize a company to distribute these lights and supply electric power to New York City.

The historic Pearl Street power station was built. On 4 September, 1882, the master switch was thrown and a number of lamps throughout downtown Manhattan gave light. The age of electricity had dawned at last.

In quick succession new power plants were built and more subscribers found the advantages of the electric light. It soon became obvious, however, that using 110-volt DC generators presented a basic problem. A mile from the generating station the power was too low to light the lamps properly. The resistance of the transmission lines was reducing the electrical pressure. Too much power was being dissipated through heat losses of the wires. Heavy wires could reduce this resistance and heat loss, but the cost of sufficiently thick wires threatened to make the entire venture uneconomical. And if the voltage were to be increased to maintain 110 volts at the end of the line, subscribers near the station

THE WORLD'S BIGGEST USERS OF ELECTRIC POWER

COUNTRY	KILOWATTS (in thousands)	KILOWATT-HOURS (in millions)
United States	288,185	1,317,300
Soviet Union	131,727	556,855
United Kingdom	55,732	196,187
Japan	49,545	237,168
Germany (West)	45,495	172,250
Canada	32,965	165,625
France	31,730	111,637
Italy	28,759	93,549
China (Mainland)	15,100	49,000
India	13,329	40,513
Sweden	13,293	53,079
Spain	12,645	38,955
Germany (East)	11,522	56,746
Australia	11,495	39,771
Norway	11,084	52,866
Other Countries	153,537	569,384
WORLD TOTAL	906,143	3,750,885

Source: U.S. Federal Power Commission

would receive so much voltage that it might burn out their lights. The problem could be solved by keeping the transmission lines short. Building generator stations near the consumers meant numerous small and relatively inefficient plants, but it seemed to be the only apparent solution.

Start of a Revolution

While the advocates of DC were building more small plants, a radically different approach was being used not far away. This new electrical distribution system, tried experimentally at first by William Stanley in Great Barrington, Massachusetts, in 1885, was put into commercial operation by George Westinghouse in 1886 at Buffalo, New York. The unique asset of this system was that power was transmitted at very high voltages while customers, regardless of their distance from the power plants, were receiving their electricity at the same low voltage. What made it possible was alternating current, working together with one of the most important electrical devices ever invented, the *transformer*.

Transformers to the Rescue

A very simple device with no moving parts, the transformer can change the voltage of an alternating current without consuming any appreciable amount of power. William Stanley developed the first practical transformer.

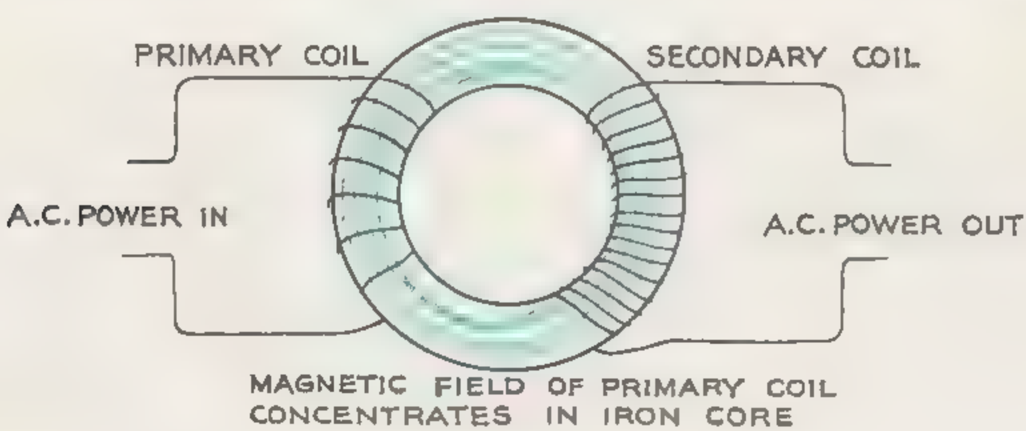
Basically, a transformer consists of two independent coils of wire wound around an iron core. The transformer is built so that the magnetic field of the first or *primary* coil can exert an influence on the other or secondary coil.

When a current passes through the primary coil it sets up a magnetic field. When the current alternates (changes its direction), so does the polarity of its magnetic field. Therefore, as the current in the primary alternates, the magnetic field of the primary builds up first in one direction, collapses, then builds up in the opposite direction, collapses again etc. Because of the iron core, practically all of this magnetic field passes through the secondary coil. Each time the lines of force of the magnetic field rise and fall, they "cut" the wires of the secondary coil. This cutting action, as Faraday had shown, induces an electromotive force and therefore a current. Since the field which created it alternates, this induced current also alternates at the same frequency.

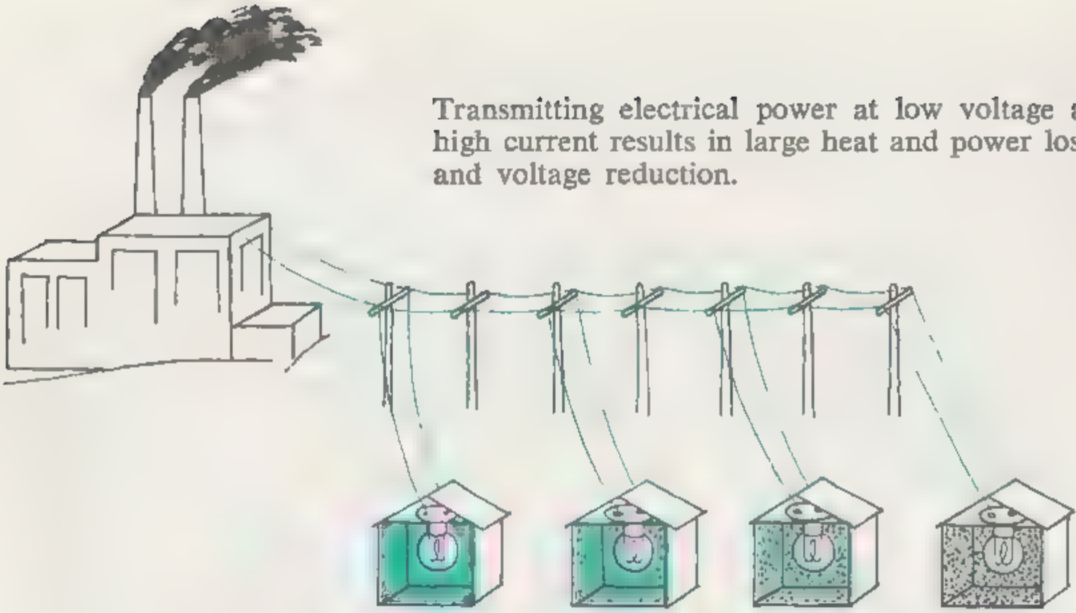
The amount of *emf* or voltage in the secondary coil depends upon how many turns of wire it has in comparison with the primary. If there are twice as many turns in the secondary, twice as much voltage is produced. But since the amount of power going through the transformer is unchanged, the amount of current produced is halved. Transformers that have more turns in the secondary coil produce higher voltages and are called *step-up* transformers. When there are half as many turns in the secondary the voltage is halved and the current is doubled. A transformer that reduces voltage is called a *step-down* transformer.

The transformer permits the economical transmission of electrical power over great distances. Power plants may be built where their generators can be turned by natural power, such as water turbines at Niagara Falls. Power is transmitted for hundreds of miles at very high voltages with correspondingly low current for negligible heat losses. At the end of the line, step-down transformers convert the power to safe low voltage and high current. As Faraday had shown, *emf* is induced only when conductors are cutting a magnetic field. A constant direct current will not operate a transformer because the conductors and magnetic field are "standing still".

TRANSFORMER CHANGES VOLTAGE OF ALTERNATING CURRENT



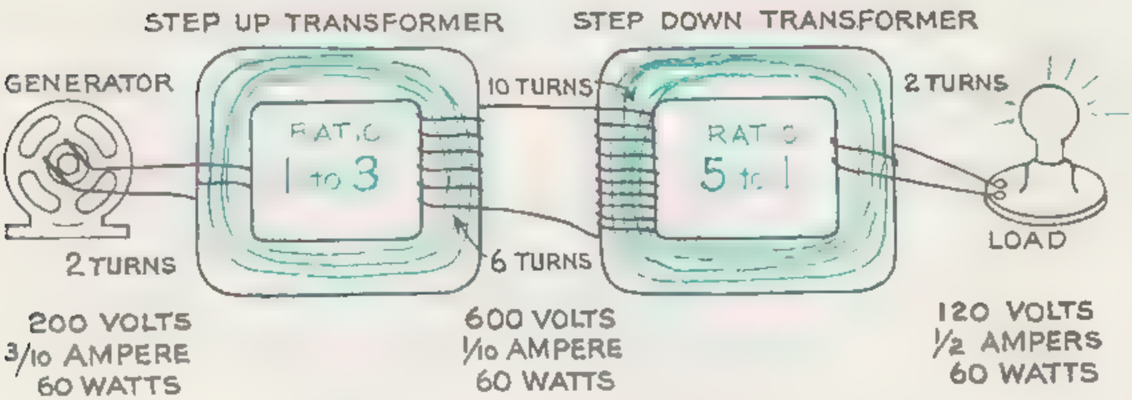
Magnetic field produced by current in the primary coil induces an alternating current in the secondary coil.



Transmitting electrical power at low voltage and high current results in large heat and power losses and voltage reduction.

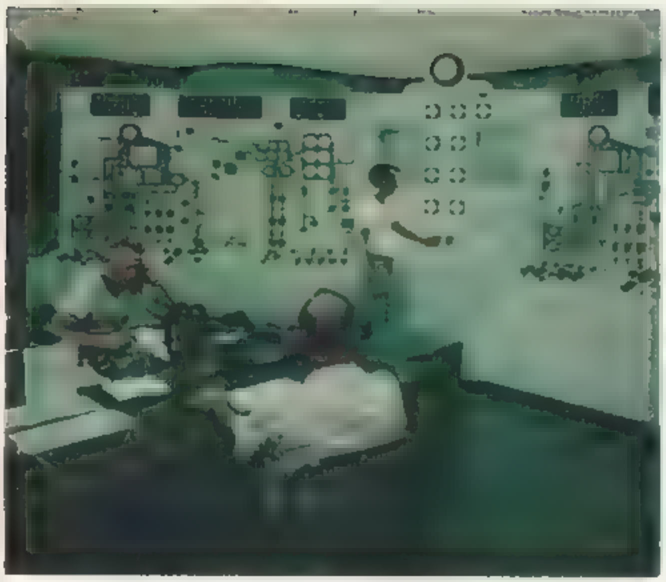
Squirrel Cages and Motors

THE VALUE OF ALTERNATING CURRENT was enhanced in 1888 when Nikola Tesla patented a motor that would operate from alternating current. Called an *induction motor*, it is similar to a DC motor in that the reaction of two magnetic fields provides the turning action. The induction motor field magnet, called the *stator*, is similar to that of a DC motor.



Very little power is lost in a transformer. The ratio of secondary voltage to primary voltage approximates the ratio of the number of turns.

This is the master control panel of the Saguaro power plant in Redrock, Arizona. From here the plant's output is sent to various substations in order to "spread the load" as evenly as possible.



8. MASTER CONTROL PANEL

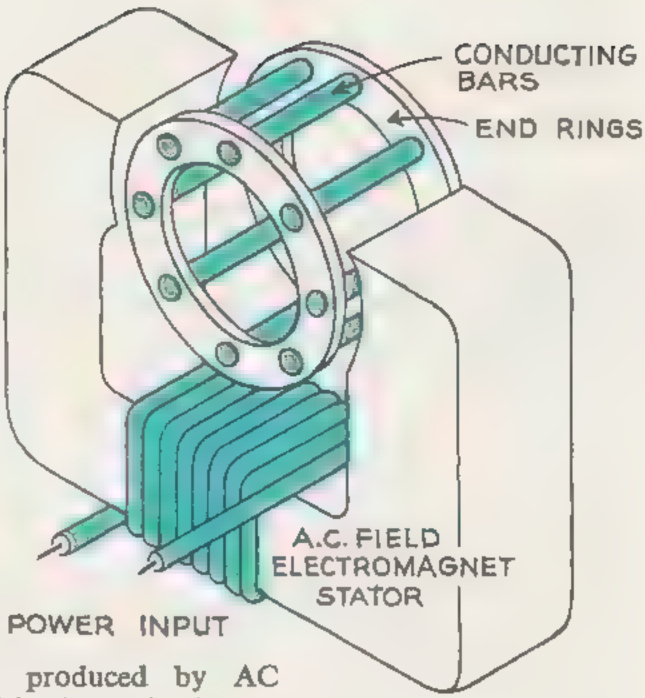
But the *rotor* (comparable to the armature of a DC motor) is radically different, for it is not connected electrically to anything else. The alternating current flowing through the stator coils sets up a magnetic field between the stator poles and continually reverses their polarity. The rotor, composed of two rings joined by straight conductors, is free to turn between these two poles and is affected by this field. The appearance of the rotor has led engineers to call it a squirrel-cage rotor.

A combination of "cutting" (due to rotation) and transformer-type action induces electromotive force in the conductors. This causes currents to circulate in the rotor. The circulating currents set up their own magnetic field which reacts with those of the stator to provide the force that makes the rotor spin. Most home appliance induction motors are called *split-phase* induction motors because they have two sets of field coils. The second set of coils helps the motor get started. The induction motor is relatively trouble-free since it has no brushes to wear out.

Some appliances in the home utilize a *universal* motor that can be run from either AC or DC. The universal motor is a DC motor with the field magnet coil and armature connected in series.

Another type of alternating current motor is the *synchronous* motor, used in electric clocks. The speed of a synchronous motor is dependent upon the frequency (cycles per second) of the source of electricity. Most regions have electricity alternating at sixty cycles per second. The

The rotor of an AC induction motor with no electrical connections to it is sometimes called a squirrel cage.



The alternating magnetic field produced by AC power induces the voltage needed in the squirrel cage.

power companies have expensive, complex equipment to regulate their generators to supply electricity at exactly sixty cycles. A synchronous motor is, in effect, "slaved" to the power station generators. It therefore benefits from the expensive controllers, and users get an accurate timepiece in an inexpensive clock motor. Synchronous motors are also used in the best phonographs and tape recorders for even-speed regulation.

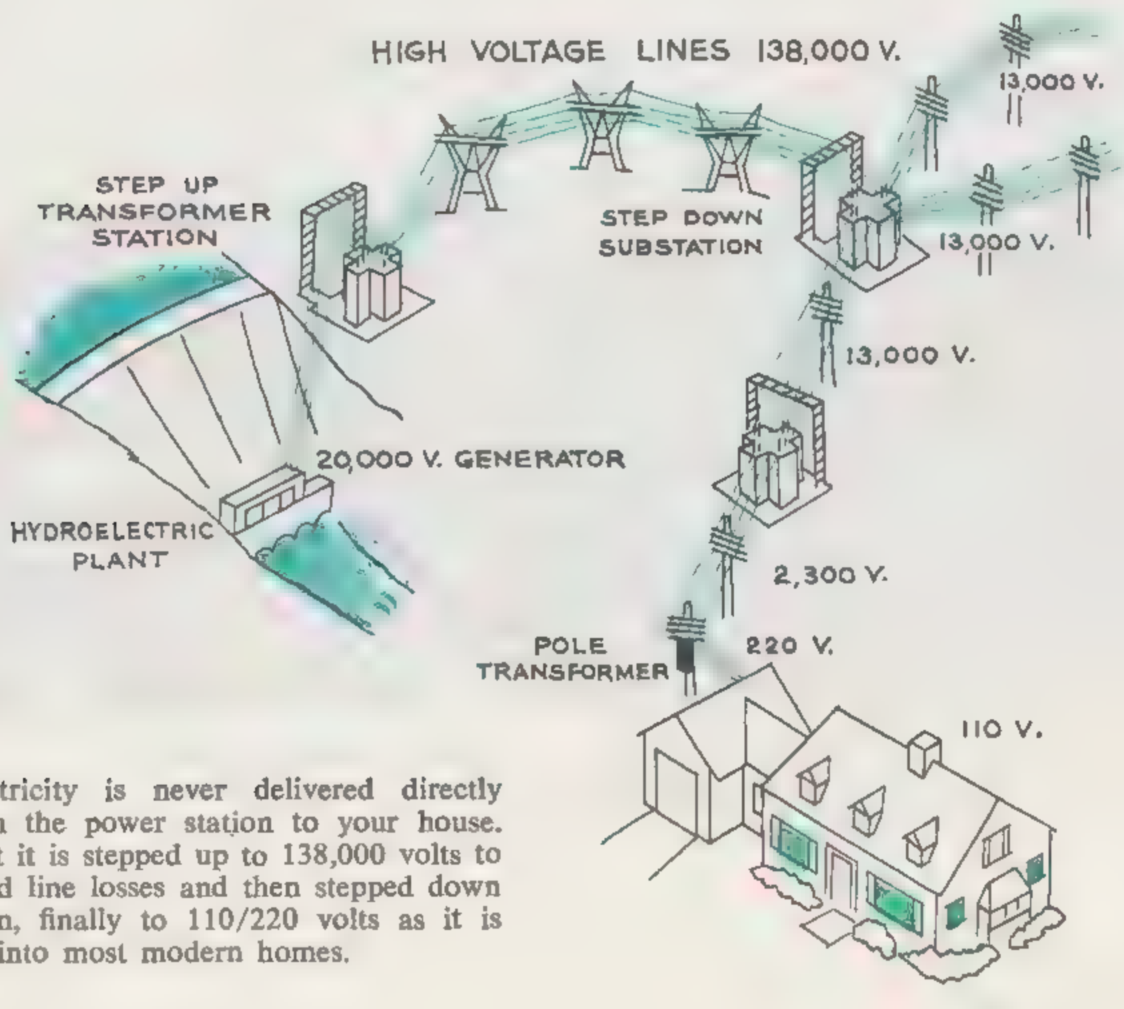
From Dam to Consumer

One of the most common sources of energy for the generation of electrical power today is water power. The dam stores water behind it in a reservoir that is accumulated from rivers and tributaries. Through the bottom of the dam are huge water pipes with valves that can regulate the amount of water flowing through them. As the pressure from above pushes the water through these tubes, the flow turns giant water wheels or turbines. The turbines spin electric generators.

Where natural water power is not available, power stations are built that use fuels to create heat that makes steam to turn steam turbines.

Coal, oil, natural gas and, increasingly, atomic energy, are used to make heat. About three-quarters of all electrical power in the United States comes from these sources. The original source of power for all electricity stems, of course, from mother nature herself: falling water, sun energy stored in fuels, or energy contained in atoms.

Grand Coulee Dam power plant is generating 5,574,000,000 watts of power, or the equivalent of almost seven million horse power. The generators at a typical electric plant produce electricity at 20,000 volts. Huge transformers increase this to 138,000 volts to provide the necessary pressure to send the electricity on the long journey to customers miles away. Some power companies are now experimenting with electricity transmission at half a million volts! As the transmission lines reach communities and cities, the voltage may be stepped down at main substations by other transformers to about 13,000 volts, and then at smaller substa-



Electricity is never delivered directly from the power station to your house. First it is stepped up to 138,000 volts to avoid line losses and then stepped down again, finally to 110/220 volts as it is fed into most modern homes.

tions to 2,300 volts. Just before it enters your home, the electricity is again reduced in voltage. If you look out of your window you will probably see a transformer attached to the utility pole in front of your house or just down the street. This gives 110 volts, or two separate circuits totaling 220 volts. Just as the power lines enter your house, they meet your main fuse box—your home's electrical safety valve.

This atomic power station at San Clemente, California, provides enough electricity to supply a city of more than a half-million population.

9. BLACK CANYON DAM, IDAHO

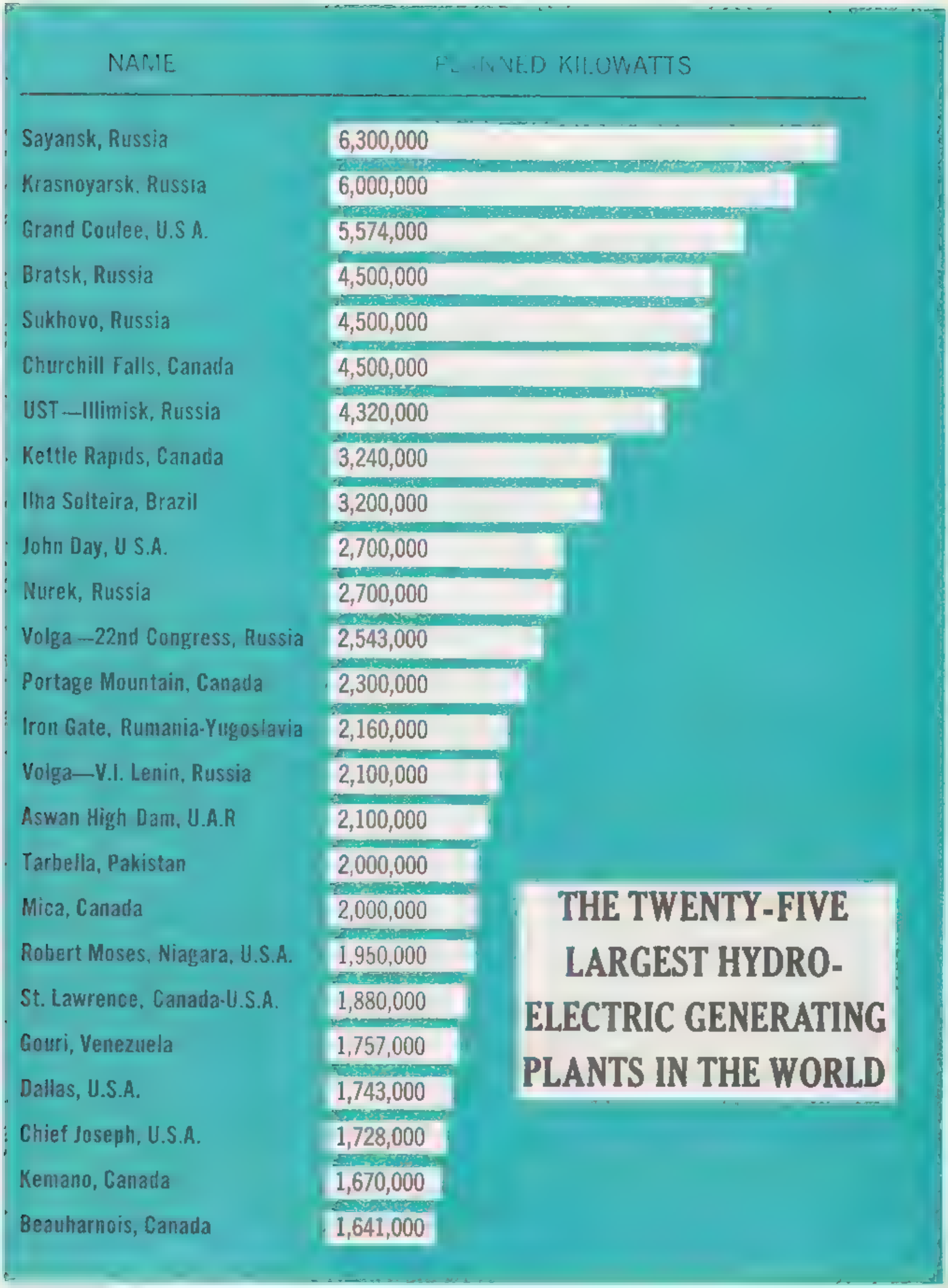
The Black Canyon Dam in the Payette River near Emmett, Idaho.

What the Future Holds

ELECTRIC POWER is essentially a privilege of the world's affluent nations. The U. S. Atomic Energy Commission reports that about 2 billion people have no electricity to live and work by. On the massive Asian continent, where one-half of the world's population resides, the electric power expended is about one-tenth of the world's total.

The United States is the biggest user of electric power. It consumes more than one-third of the world's total. The Federal Power Commission calculates that the United States should double its electric power output every ten years. Having expended about 300 million kilowatts at the end of 1970, the United States ordinarily would be expected to use 1,260 million kilowatts in 1990.

This voracious demand for electricity, however, has introduced serious problems for American consumers. Reserve capacities of electric power have not always been sufficient; demand has exceeded the planned use. "Brownouts" and "blackouts"—power shortages and emergency reductions in power—have proved a routine occurrence in many regions of the United States, particularly during hot summer months. When a city such as New York experiences power blackouts, hundreds of thousands of citizens are left without electricity for several hours; millions of others may be


NAME
KILOWATTS
Sayansk, Russia 6,300,000
Krasnoyarsk, Russia 6,000,000
Grand Coulee, U.S.A. 5,574,000
Bratsk, Russia 4,500,000
Sukhovo, Russia 4,500,000
Churchill Falls, Canada 4,500,000
UST—Illimisk, Russia 4,320,000
Kettle Rapids, Canada 3,240,000
Ilha Solteira, Brazil 3,200,000
John Day, U.S.A. 2,700,000
Nurek, Russia 2,700,000
Volga—22nd Congress, Russia 2,543,000
Portage Mountain, Canada 2,300,000
Iron Gate, Rumania-Yugoslavia 2,160,000
Volga—V.I. Lenin, Russia 2,100,000
Aswan High Dam, U.A.R 2,100,000
Tarbella, Pakistan 2,000,000
Mica, Canada 2,000,000
Robert Moses, Niagara, U.S.A. 1,950,000
St. Lawrence, Canada-U.S.A. 1,880,000
Gouri, Venezuela 1,757,000
Dallas, U.S.A. 1,743,000
Chief Joseph, U.S.A. 1,728,000
Kemano, Canada 1,670,000
Beauharnois, Canada 1,641,000
THE TWENTY-FIVE LARGEST HYDRO-ELECTRIC GENERATING PLANTS IN THE WORLD

A familiar sight throughout the United States, the pylon is part of a vast network that supplies current to almost all American homes and factories.

10. 138,000 VOLTS

directed to reduce their electric usage; the subway is forced to slow to half-speed.

Some experts say that electricity may have to be rationed in the future, if something is not done to reverse the current trend of inadequate reserve power supplies.

Not only has demand started to outrun supply in many areas, but an energy crisis brought on by irregularities in the flow of petroleum from the Middle East, plus skyrocketing prices for fuel, has aggravated the electric power situation. It was to save the equivalent of 95,000 barrels of oil a day, for example, that the United States went on Daylight Savings Time on a year-round basis in 1974. The idea was to save electricity in the evening hours by providing additional daylight.

Atomic Power Comes of Age

SCIENTISTS ARE ENDEAVORING to find ways to alleviate the energy crisis, and atomic power plants are very much in the cards as a growing source of electricity. The era in which electricity is furnished by atomic reactors started in the early 1950s, with Britain leading the way. The

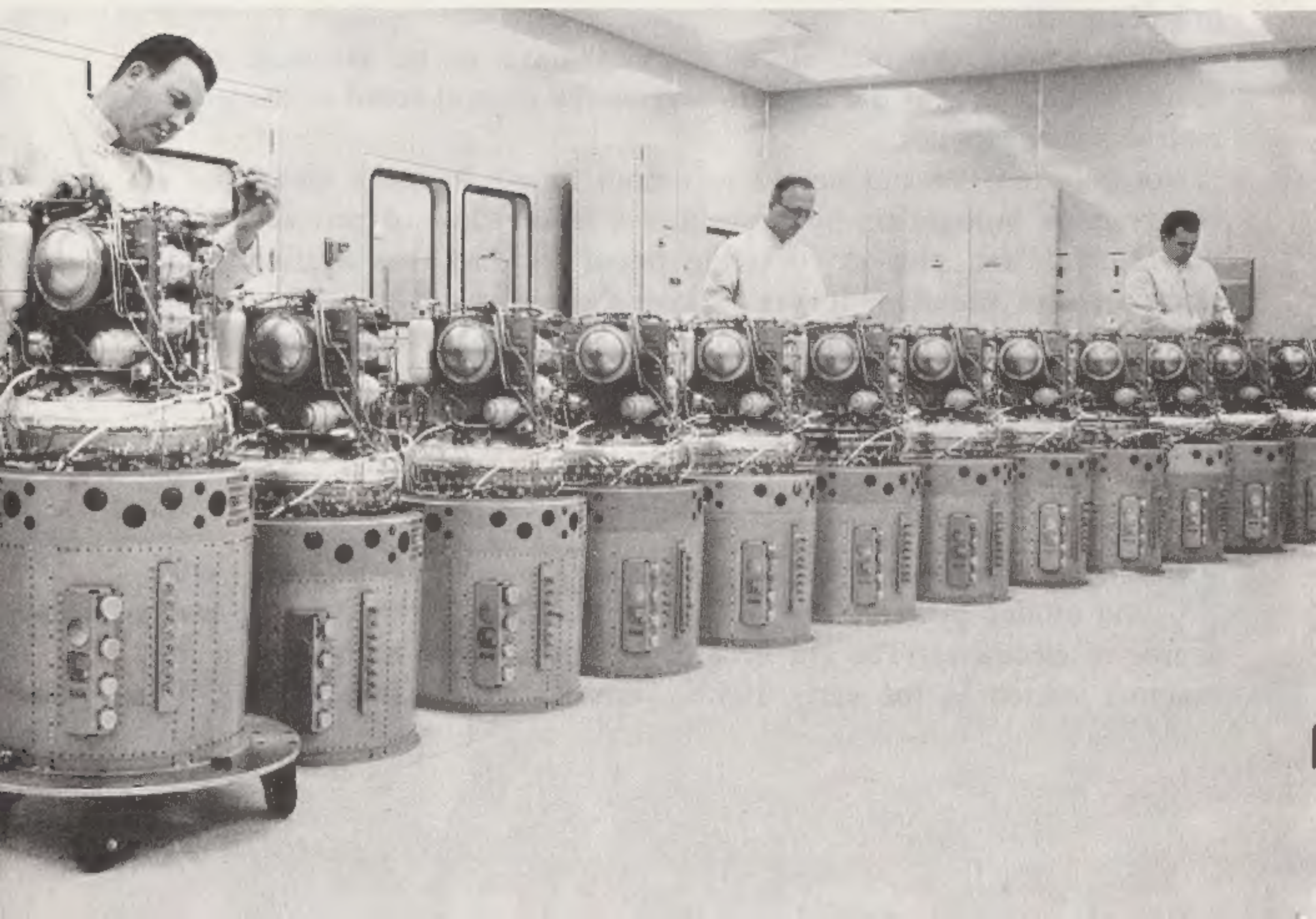
60,000-kilowatt Shippingport atomic power station near Pittsburgh began operating in late 1957 as America's first full-scale nuclear power plant strictly for civilian purposes.

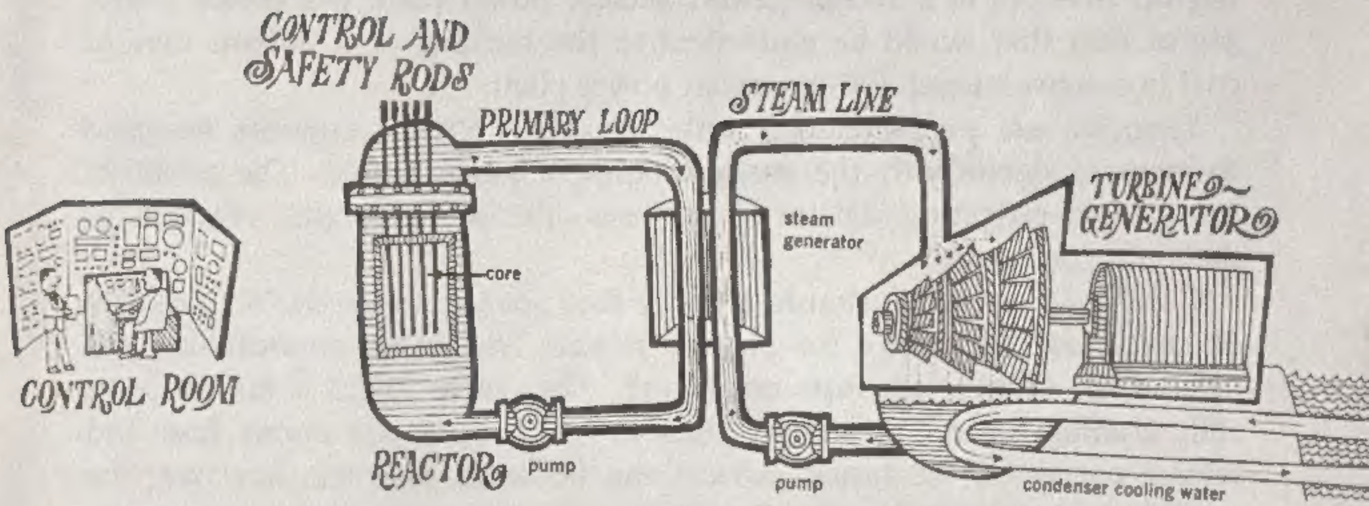
By 1974, there were more than twenty-five nuclear power plants in operation in the United States, and they provided more than three per cent of the electric power turned out in the country.

By the year 2000, the Atomic Energy Commission predicts the United States should have hundreds of atomic-powered plants, which would furnish about one-half of the nation's electric power. Most of the world's power is supplied today by coal, oil and gas. However, these fuels are not limitless, and scientists more and more are betting on nuclear energy to fulfill the power needs of the twenty-first century. They hope, in the interim, to convince environmentalists that atomic power plants do not pose unacceptable dangers to surrounding areas.

Nuclear power plants today are producing the heat to boil water and make steam to operate the large turbine generators much like the coal-burning power stations. The major difference is that the tremendous heat

These twelve fuel cell power plants were built to provide on-board electrical power for Apollo spacecraft.





Pressurized Water Plant

The Westinghouse Pressurized Water Reactor system operates two separate systems, or loops, of circulating water. Water in the so-called primary loop is kept under pressure to prevent it from boiling. It is pumped through the nuclear reactor, where it picks up heat from the nuclear core of enriched uranium, raising its temperature to about 619° F. This water then passes through a steam generator, giving up its heat to water in a secondary loop. Then the primary loop water returns to the reactor to pick up more heat. Because the water in the secondary loop is under lower pressure, the heat turns it to steam. The steam is carried through pipes to a turbine where it rushes against the blades on the turbine shaft and turns the shaft at a speed of 1,800 revolutions per minute. The turbine shaft turns the generator shaft at the same speed and the generator produces electricity.

is formed in nuclear reactors by fission process in which atoms are split and radiation emitted. As a result of the fission, a very small part of the atom's mass (uranium isotope 235) is converted into energy which propels neutrons and other particles at high speed and thereby provides heat. A neutron released by fission of one atom can strike another atom of U 235 and make it fission in turn. Continuation of this process consti-

tutes the so-called "nuclear chain reaction". Chain reactions can cause fission of billions of individual atoms which together can release great quantities of heat. The fission of one-half per cent of seventy-five tons of nuclear material in a 500-megawatt nuclear power plant will create a supply of heat that would be equivalent to the burning of a million tons of coal in a conventional 500-megawatt power plant.

Scientists are experimenting with "breeder" nuclear reactors designed to increase significantly the energy output of nuclear fuels. The scientists are also investigating the fusion process—the atom-merging reaction of the hydrogen bomb.

Controlled nuclear fusion is a tricky feat not yet mastered for purposes of supplying the energy for electric power. Nor is its applicability just around the corner, scientists conjecture. They have found it far easier to split uranium atoms for energy than to make hydrogen atoms fuse and release energy. If the fusion process can be made to work, however, the world's oceans will furnish the ideal fuel—heavy hydrogen or deuterium.

The twenty-first century could well bring forth tremendous advances in the application of electric power. Electric cars operated by batteries that store and reuse their chemical or atomic wastes are a distinct possibility. Overhead and underground wires transmitting electric current may become obsolete and in their place radio waves may transfer electricity. Solar batteries put to good use in satellites today may also have wider application on earth. With the twenty-first century not far off, electricity could soon be entering an enterprising new era.

SCIENCE SERVICE

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